ASQG
the Good, the Bad and the Ugly

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Overview

- **ASQG** — a lightning introduction
- **The Good** — well-established results
- **The Bad** — manageable problems
- **The Ugly** — here be dragons

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DISCLAIMER: necessarily a biased selection, apologies for any omissions!

The bare-bones story of ASQG

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…or: ***Q**uantum **G**ravity as a **Q**uantum **F**ield **T**heory*

The bare-bones story of ASQG

several chapters in Handbook of Quantum Gravity:

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finally published, order now for the low price of ~~1278.97~~ 1111.99 EUR!

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Lectures in Quantum Gravity: 2412.08690
(perturbative QG, EFT, ASQG, ST, BHs)

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  - expected to continue to arbitrary order — **predictivity lost**

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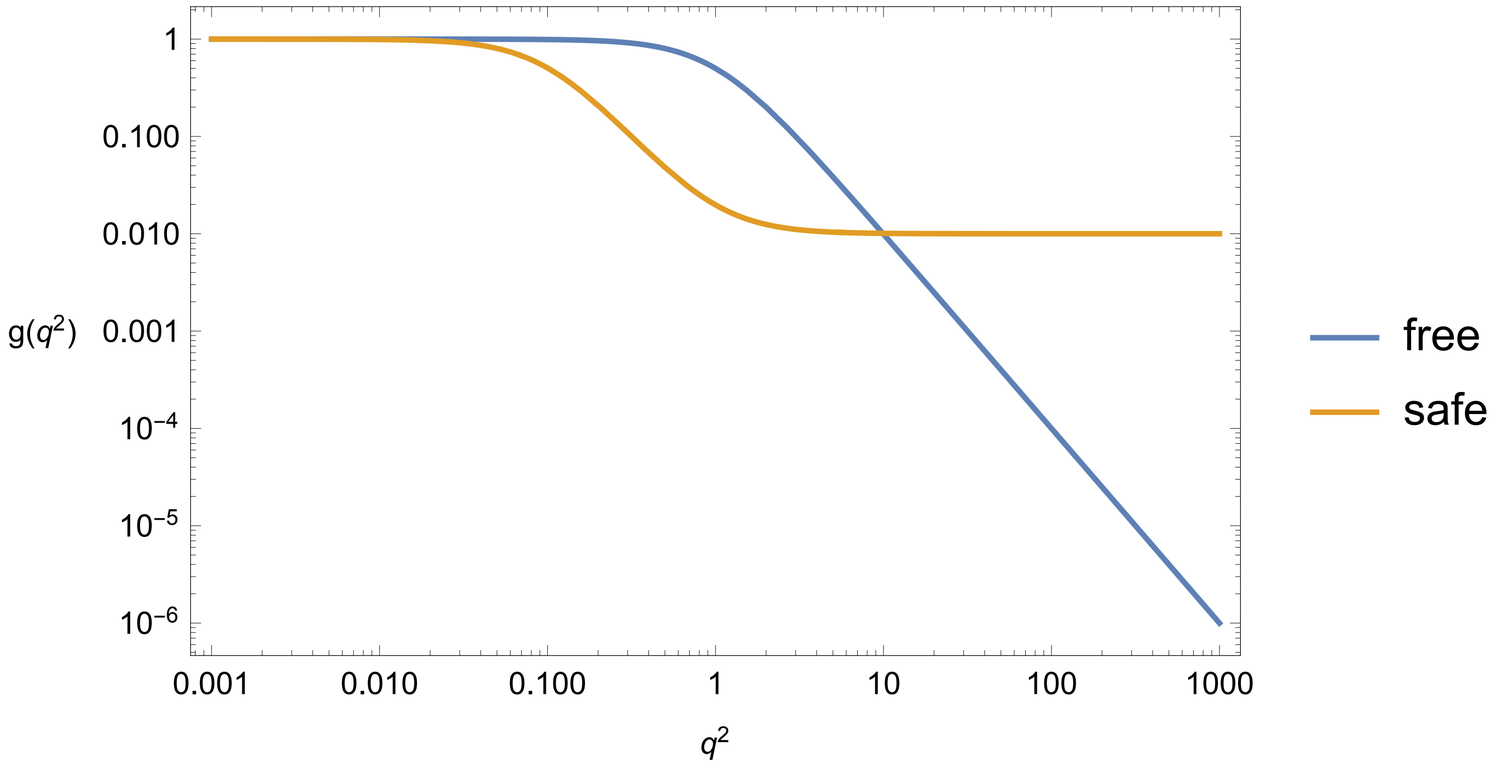

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finiteness

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    finiteness
  - only finitely many relevant operators = finitely many measurements needed to uniquely fix theory

    predictivity

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my focus today

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my focus today **many interesting results**

- **quantum Ricci curvature** *Klitgaard, Loll*
- **CDT meets YM** *Clemente, D'Elia, Németh, Simonetti*
- **CDT meets FRG** *Ambjørn, Gizbert-Studnicki, Görlich, Németh*
- **EDT meets dynamical DE** *Dai, Freeman, Laiho, Schiffer, Unmuth-Yockey*

Asymptotic Safety via FRG

- Wilsonian idea of integrating out modes shell by shell

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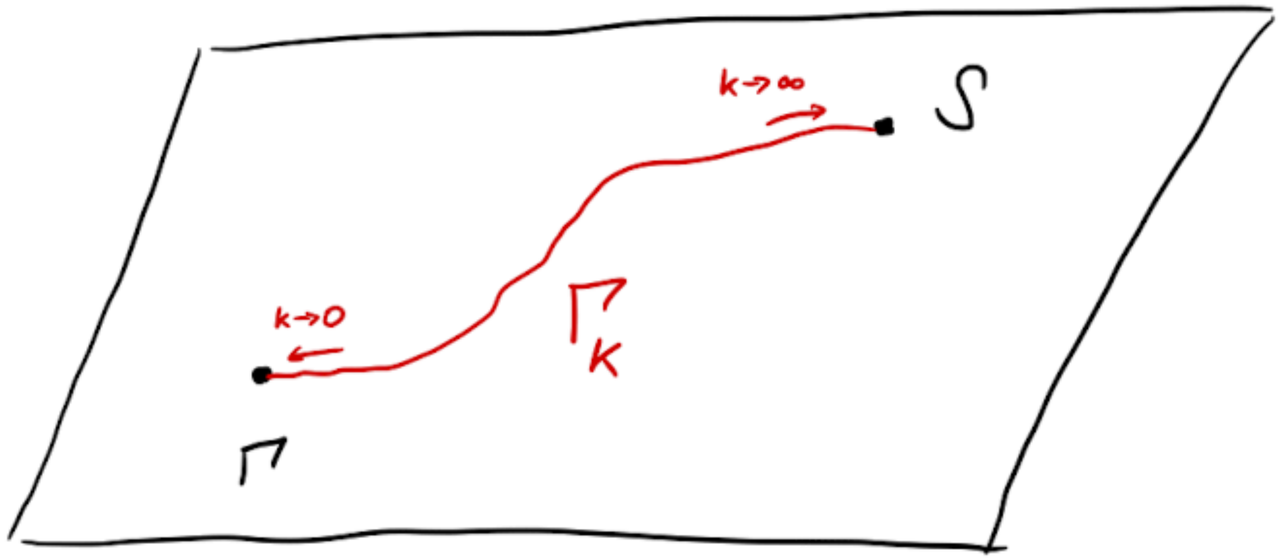

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- governed by **exact non-perturbative** RG equation:

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

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- no free lunch: requires approximation

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the happy little challenges
(what keeps me up at night)

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[Dupuis, Canet, Eichhorn, Metzner, Pawlowski, Tissier, Wschebor '20]

The Good

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…or: what *should* be on wikipedia

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- a suitable UVFP **exists** beyond reasonable doubt

ASQG community 1996-2025+

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ASQG is maximally boring

FP Existence

- derivative expansion — $\mathcal{O}(\partial^6)$ (minimal essential) / $\mathcal{O}(\partial^4)$ (standard)

Baldazzi, Falls, Kluth, BK *BK*

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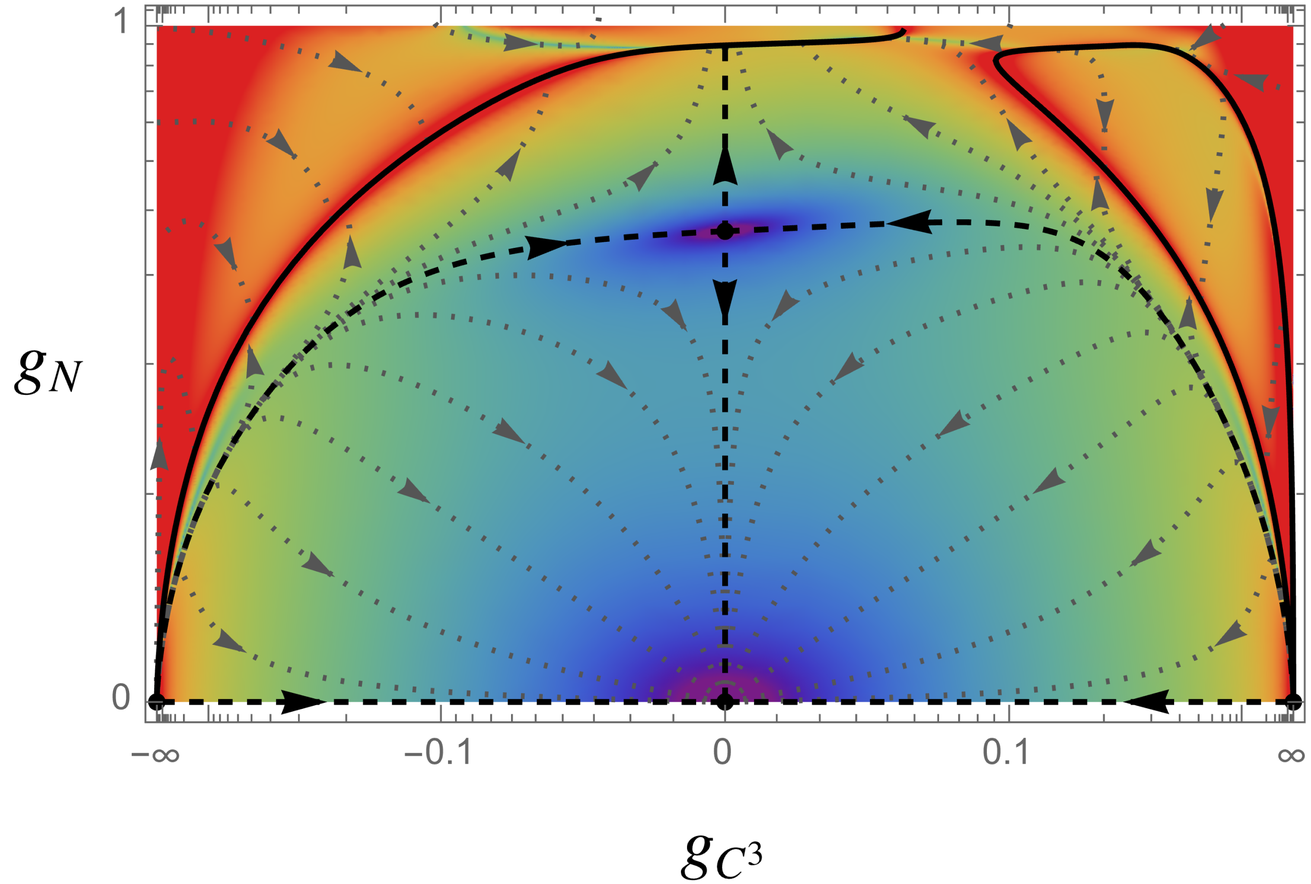

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  - easy to get spin two ghost at finite curvature

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- apparent convergence from fluctuation computations

  Christiansen, Denz, BK, Meibohm, Pawlowski, Reichert, Rodigast, Schiffer

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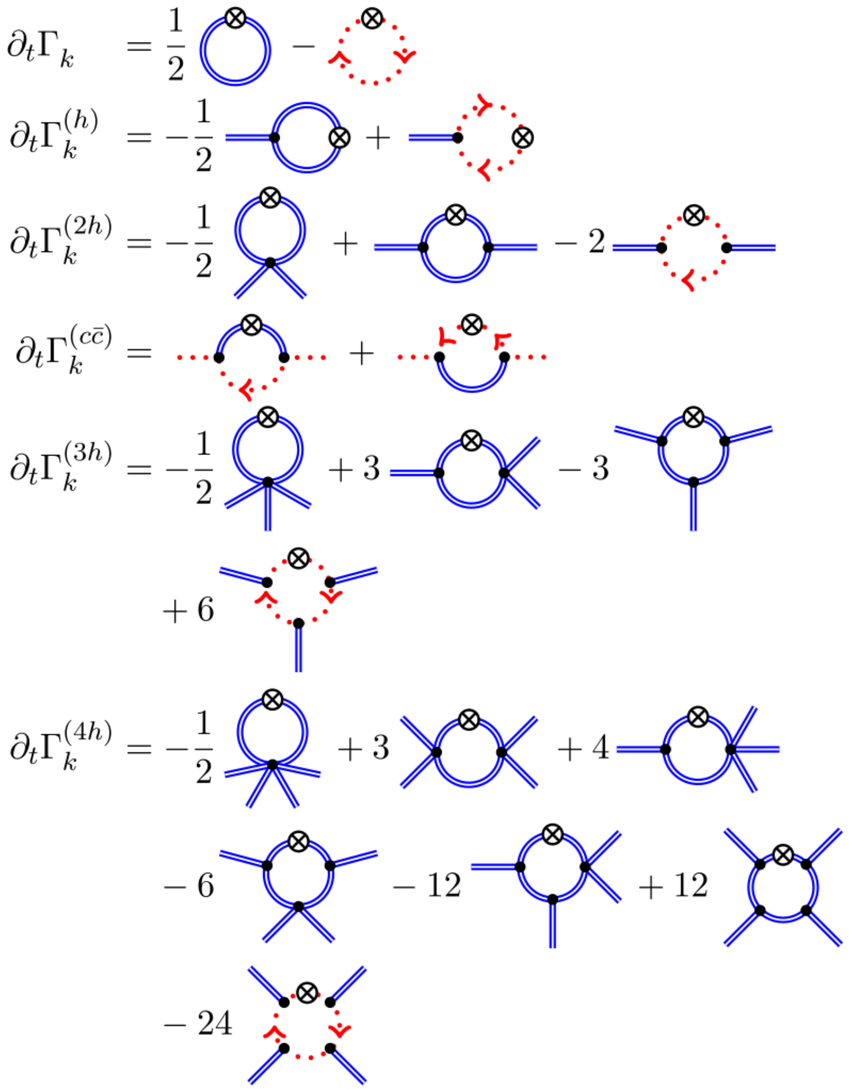

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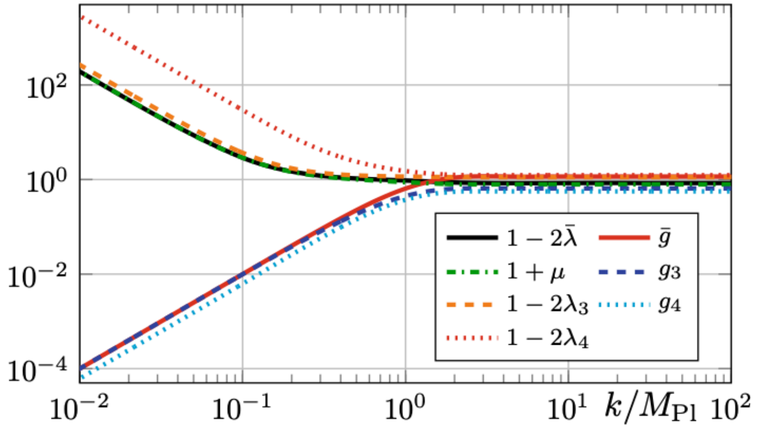

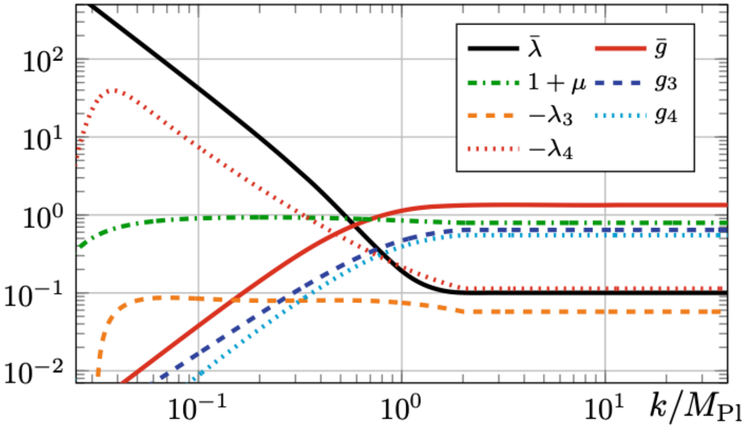

[Denz, Pawlowski, Reichert '16]

No ghosts

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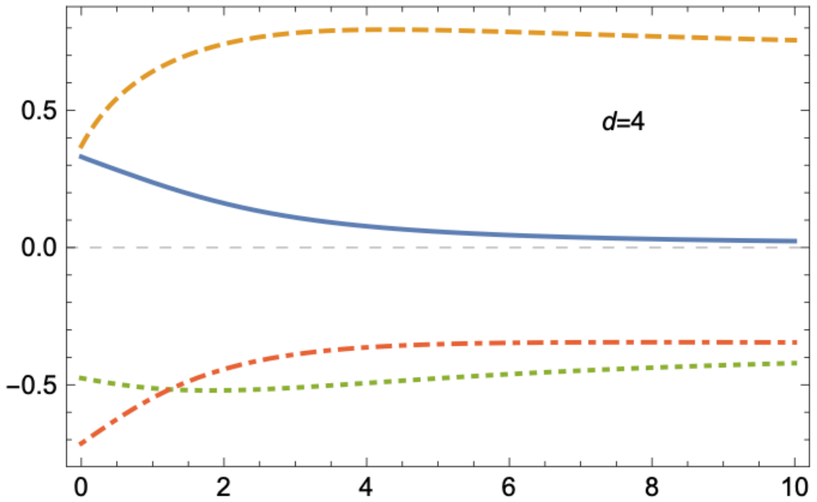
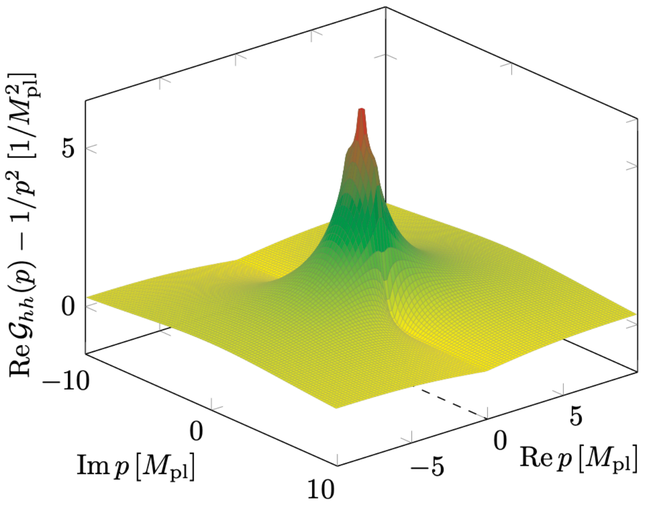
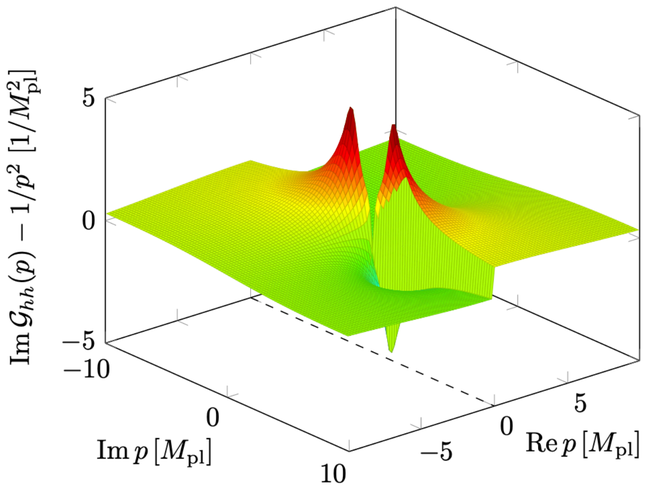


[BK, Schiffer ’21]





[Fehre, Litim, Pawlowski, Reichert ’23]

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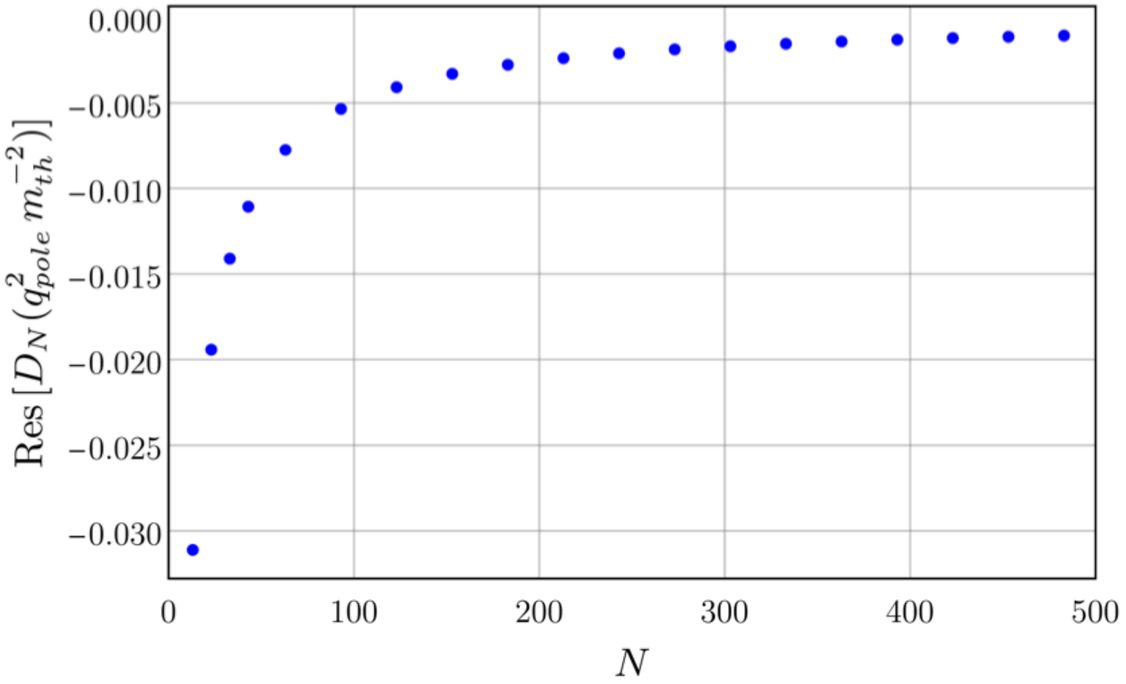

[Platania, Wetterich '20]

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- elegant way to avoid spurious poles: minimal essential scheme

Baldazzi, Ben Alì Zinati, Falls, Kluth, BK

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- small corrections to scaling in $f(R)$
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  - expect good convergence properties
  - diffeomorphism breaking limited (effective universality)
  - seems necessary for ASQG to work effectively

Eichhorn, Labus, Lippoldt, Pawlowski, Reichert, Schiffer

Gravity pheno

- tool of choice (usually): RG improvement

Bonanno, Borissova, Bosma, Gionti, Gubitosi, Held, Henz, BK, Koch, Ooijer, Pawlowski, Percacci, Platania, Reuter, Ripken, Rodigast, Saueressig, Wetterich

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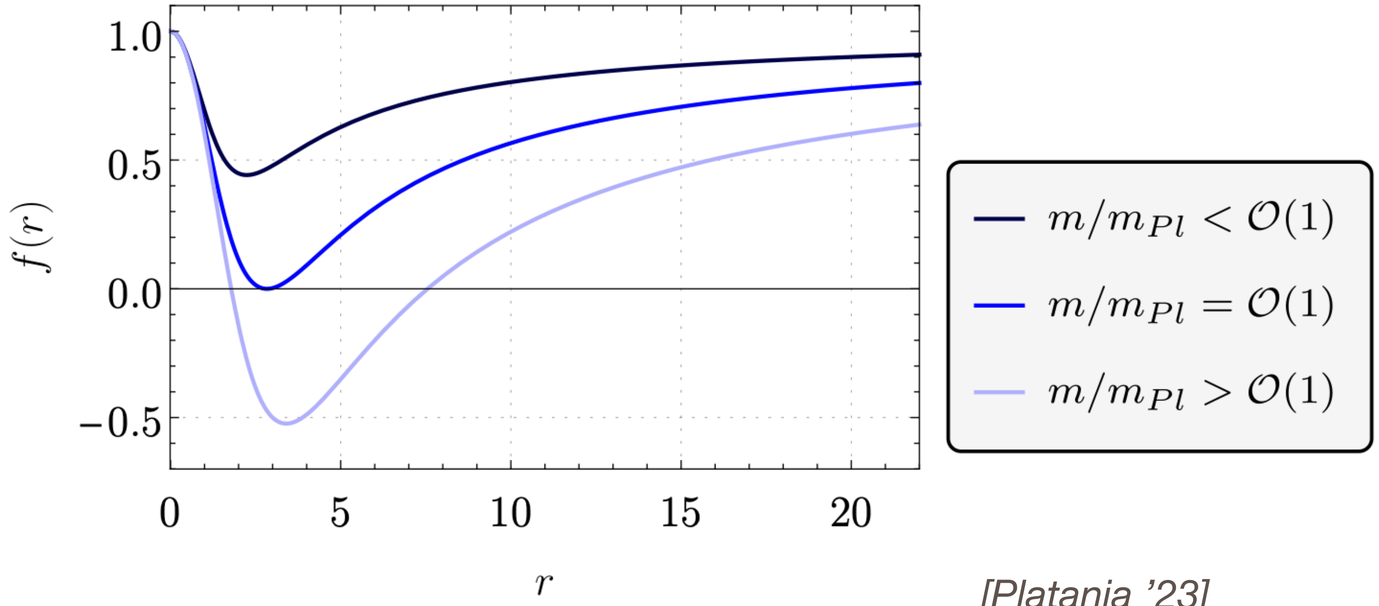

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- bouncing geometries

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ASQG community 2013-2025+

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  - SM and beyond

Effective universality

Eichhorn, Labus, Lippoldt, Pawlowski, Reichert, Schiffer

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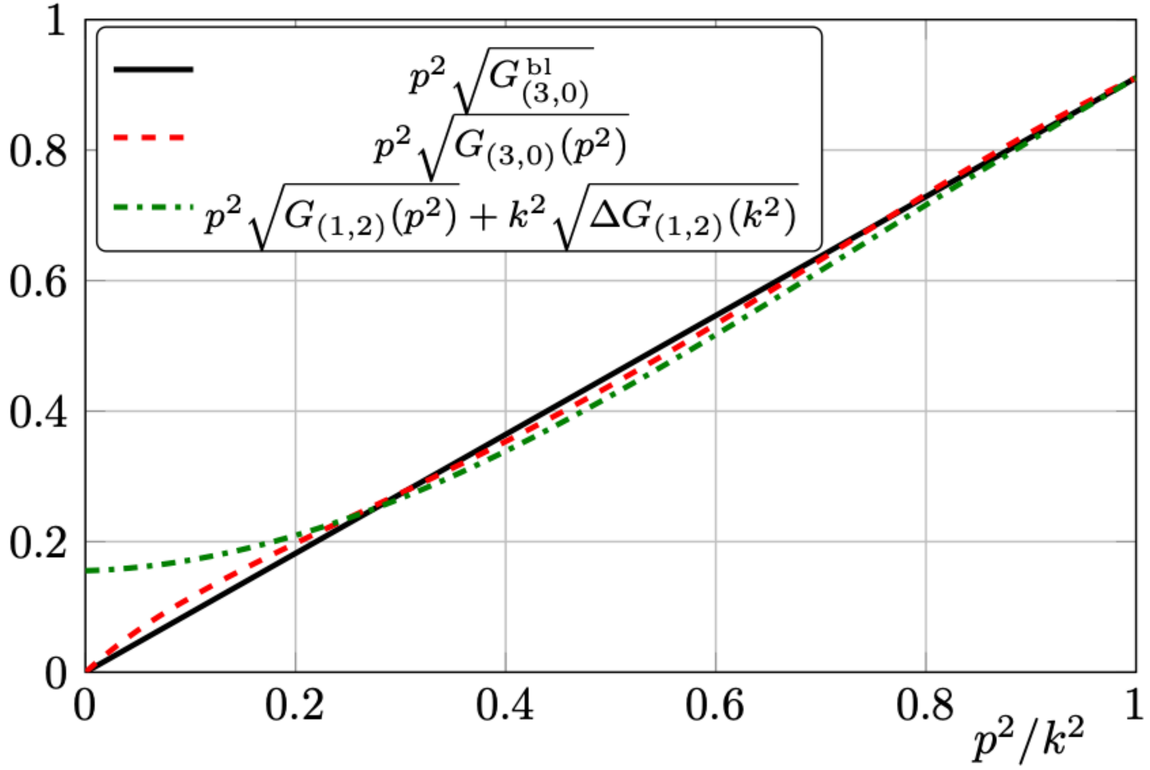


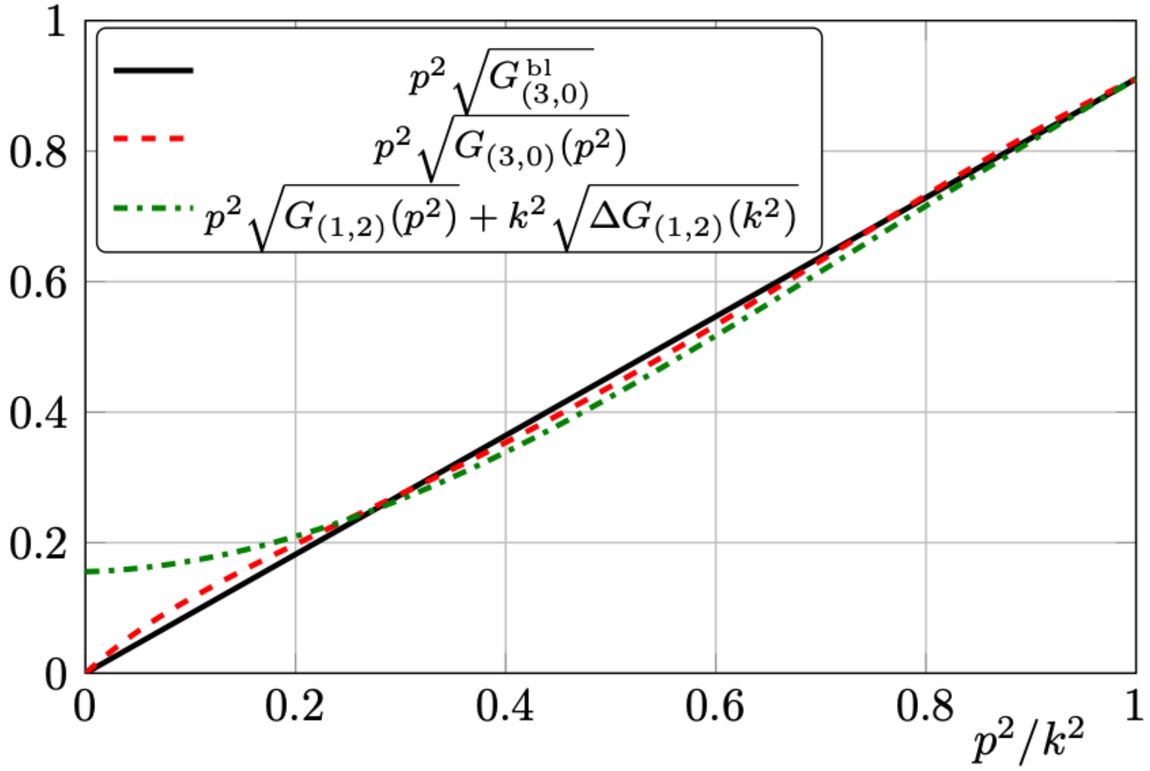
[Eichhorn, Labus, Pawlowski, Reichert '18]

Effective universality

Eichhorn, Labus, Lippoldt, Pawlowski, Reichert, Schiffer

- (partial) restoration of full diffeomorphism invariance at the fixed point

- some discrepancies left between background and fluctuation computations



[Eichhorn, Labus, Pawlowski, Reichert '18]

Bounds on matter

- minimal coupling

Alkofer, Biemans, Christiansen, Daas, Donà, Eichhorn, Hamada, BK, Labus, Laporte, Lippoldt, Litim, Meibohm, Narain, Oda, Oosters, Pawlowski, Pedersen, Percacci, Pereira, Platania, Reichert, Saueressig, Schiffer, Skrinjar, Vacca, Wang, Wetterich, Yamada

Bounds on matter

- minimal coupling
  - scalars and fermions screen gravity
  - gauge fields anti-screen gravity

Alkofer, Biemans, Christiansen, Daas, Donà, Eichhorn, Hamada, BK, Labus, Laporte, Lippoldt, Litim, Meibohm, Narain, Oda, Oosters, Pawlowski, Pedersen, Percacci, Pereira, Platania, Reichert, Saueressig, Schiffer, Skrinjar, Vacca, Wang, Wetterich, Yamada

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Bounds on matter

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- non-minimal couplings
  - some couplings cannot be free at the FP *[Eichhorn ’12]*
  - case-by-case study necessary

Alkofer, Biemans, Christiansen, Daas, Donà, Eichhorn, Hamada, BK, Labus, Laporte, Lippoldt, Litim, Meibohm, Narain, Oda, Oosters, Pawlowski, Pedersen, Percacci, Pereira, Platania, Reichert, Saueressig, Schiffer, Skrinjar, Vacca, Wang, Wetterich, Yamada

SM physics…

- key ingredient: light fermions — chiral symmetry

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  - chiral FP exists — if you don’t break chiral symmetry by hand

SM physics…

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- connect to “high”-energy physics

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Shaposhnikov, Wetterich
Eichhorn, Held

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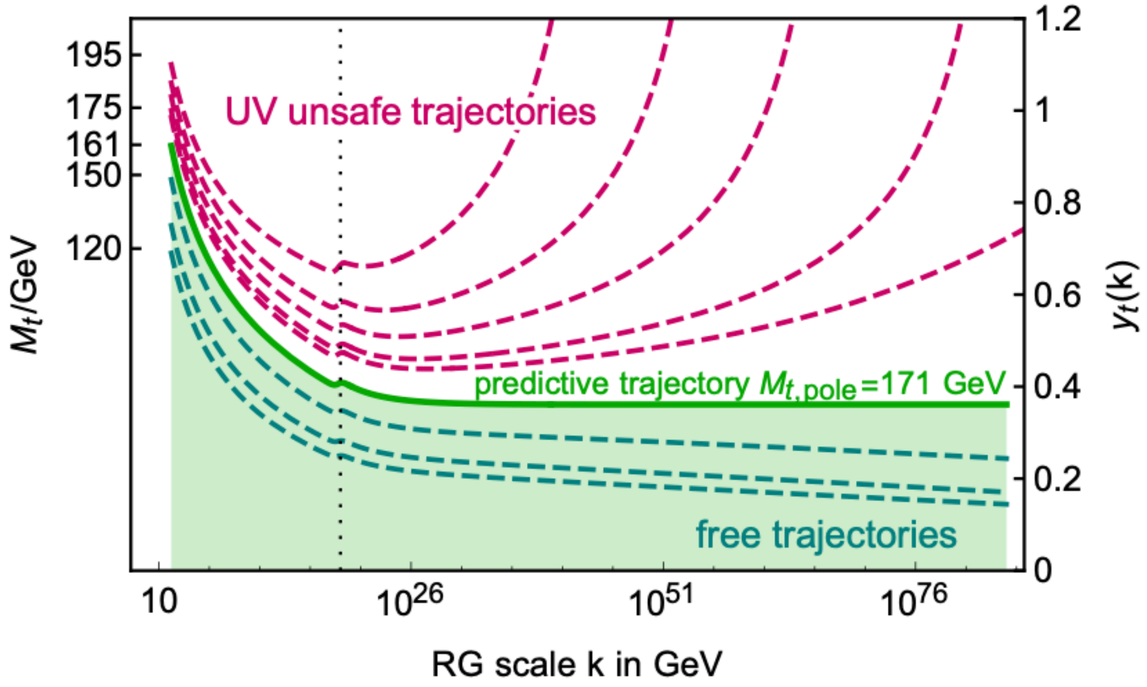
[Eichhorn, Held ’17]



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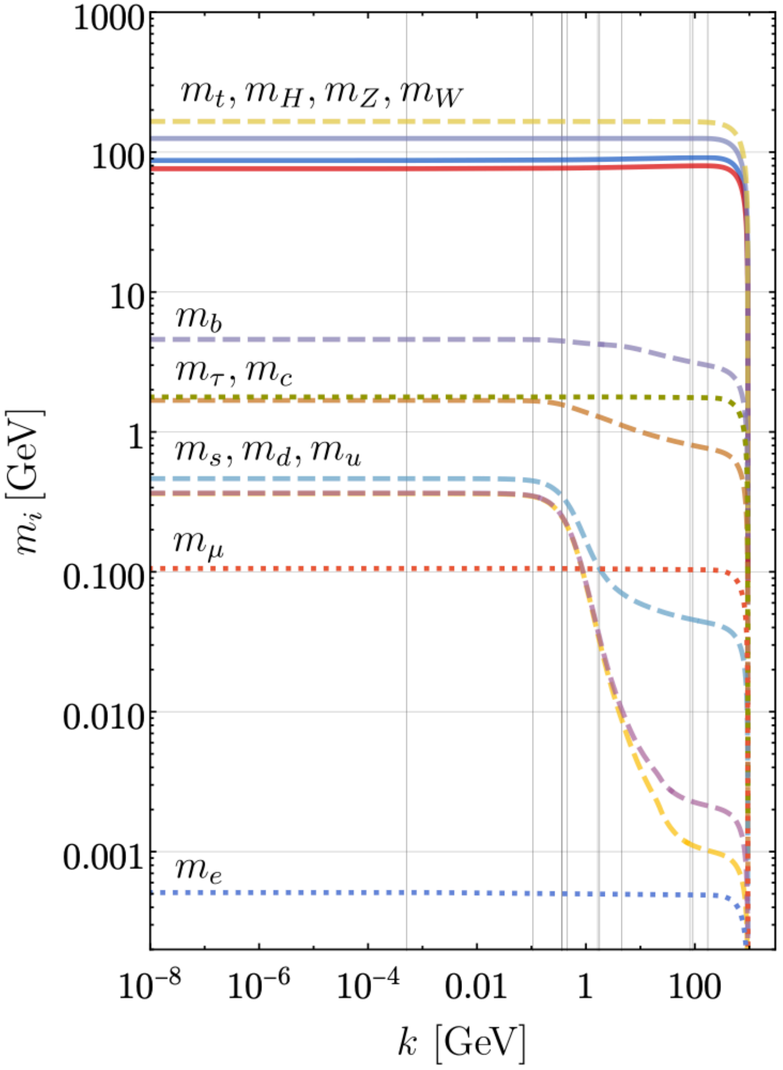
[Pastor-Gutiérrez, Pawlowski, Reichert ’23]



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Alkofer, Eichhorn, Held, Nieto, Percacci, Schröfl
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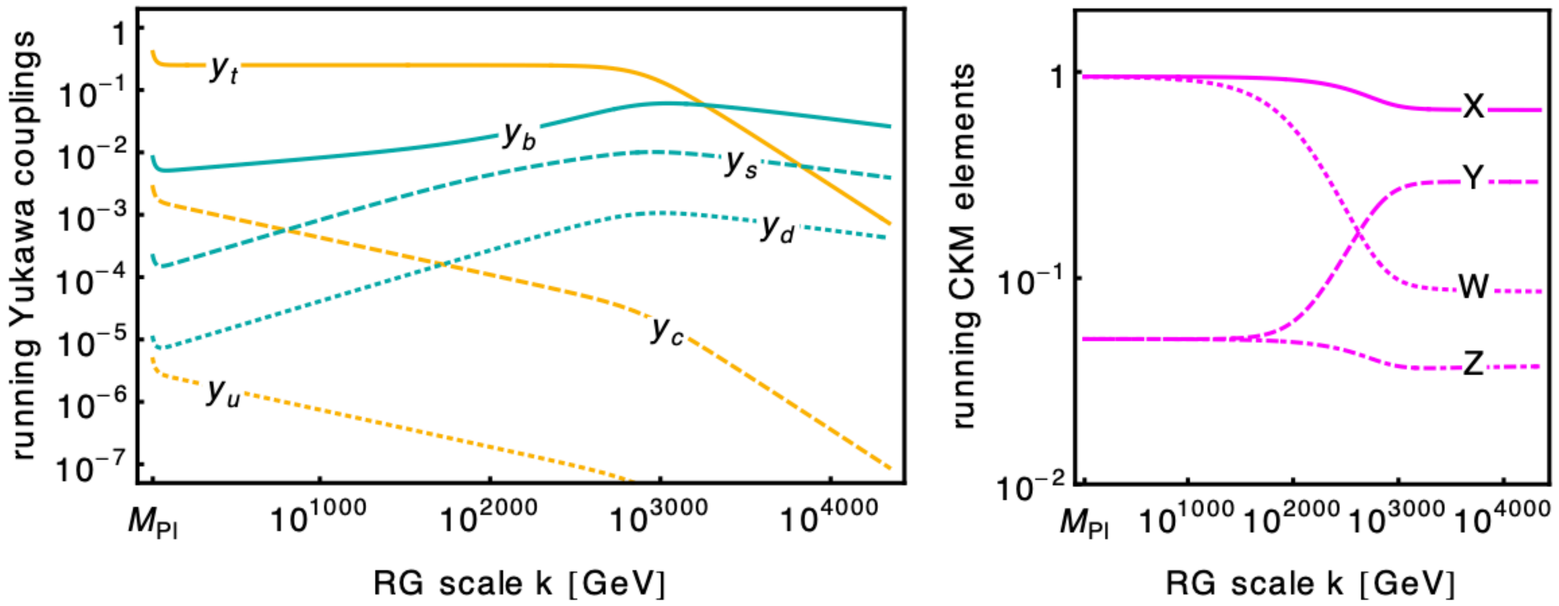

[Alkofer, Eichhorn, Held, Nieto, Percacci, Schröfl ’20]

SM physics…

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  - CKM matrix elements
  - $U(1)$ physics — upper critical dimension, upper bound for coupling, …

Christiansen, Eichhorn, Schiffer, Versteegen

…and beyond

- dark matter

de Brito, Eichhorn, Hamada, Kowalska, Lino dos Santos, Lumma, Pauly, Ray, Reichert, Sessolo, Smirnov, Yamada

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de Brito, Domènech, Eichhorn, Goodsell, Hamada, Held, Kowalska, Pereira, Pramanick, Sessolo, Wetterich, Yamada

The Bad

The Bad

…or: best bang for the buck regime

The Bad

- systematic error control

The Bad

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- diffeomorphism invariance

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- diffeomorphism invariance
- scattering amplitudes & Lorentzian signature

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Systematic error control

- “*uncontrolled approximations*”

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- systematically improve approximation

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- take inspiration from condensed matter physics:

Balog, Chaté, Delamotte, Marohnic, Wschebor

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  - derivative expansion in Ising model has finite radius of convergence

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  - derivative expansion in Ising model has finite radius of convergence
  - e.g. relevant critical exponent

$$\partial^6: \quad 1/\theta = 0.63012(5)$$
$$\mathrm{CBS}: \quad 1/\theta = 0.629971(4)$$

Diffeomorphism invariance

- "*gauge-invariant flow equation*" — pick your flavour

Falls, Morris, Wetterich
Ihssen, Pawlowski

Diffeomorphism invariance

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- different paths to restore full diffeomorphism invariance

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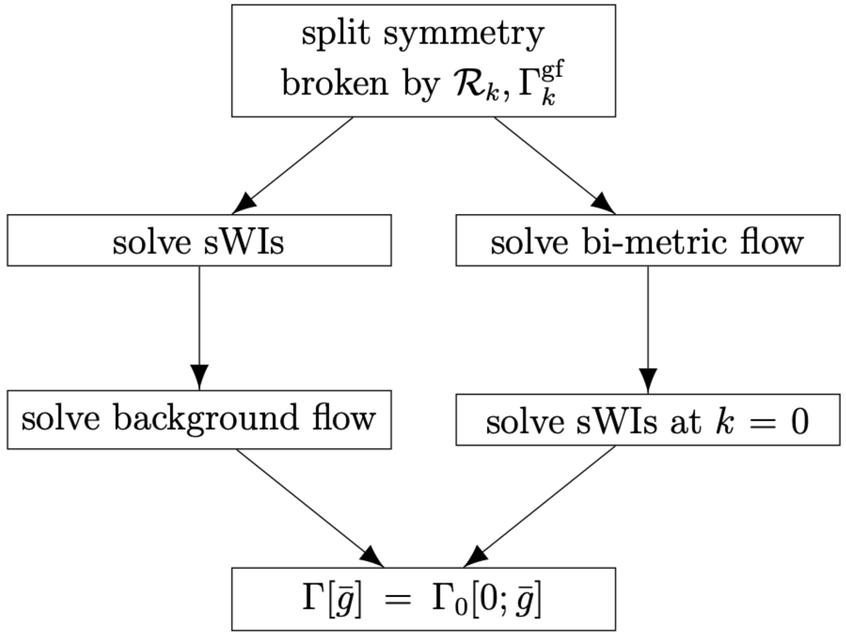
Falls, Morris, Wetterich Ihssen, Pawlowski

Donkin, Labus, Litim, Manrique, Morris, Nieto, Pawlowski, Percacci, Preston, Reuter, Safari, Saueressig, Skrinjar, Slade, Vacca



Becker, Bonanno, Christiansen, Codello, de Brito, Denz, D'Odorico, Eichhorn, Falls, Fehre, Held, BK, Litim, Lippoldt, Manrique, Meibohm, Pagani, Pastor-Gutiérrez, Pawlowski, Reichert, Reuter, Rodigast, Ruisi, Saueressig, Schiffer

[BK, Ripken, Saueressig '19]

Scattering amplitudes & the pesky minus sign

- "*something something observables*" — scattering amplitudes are useful [citation missing]

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- foliated flows

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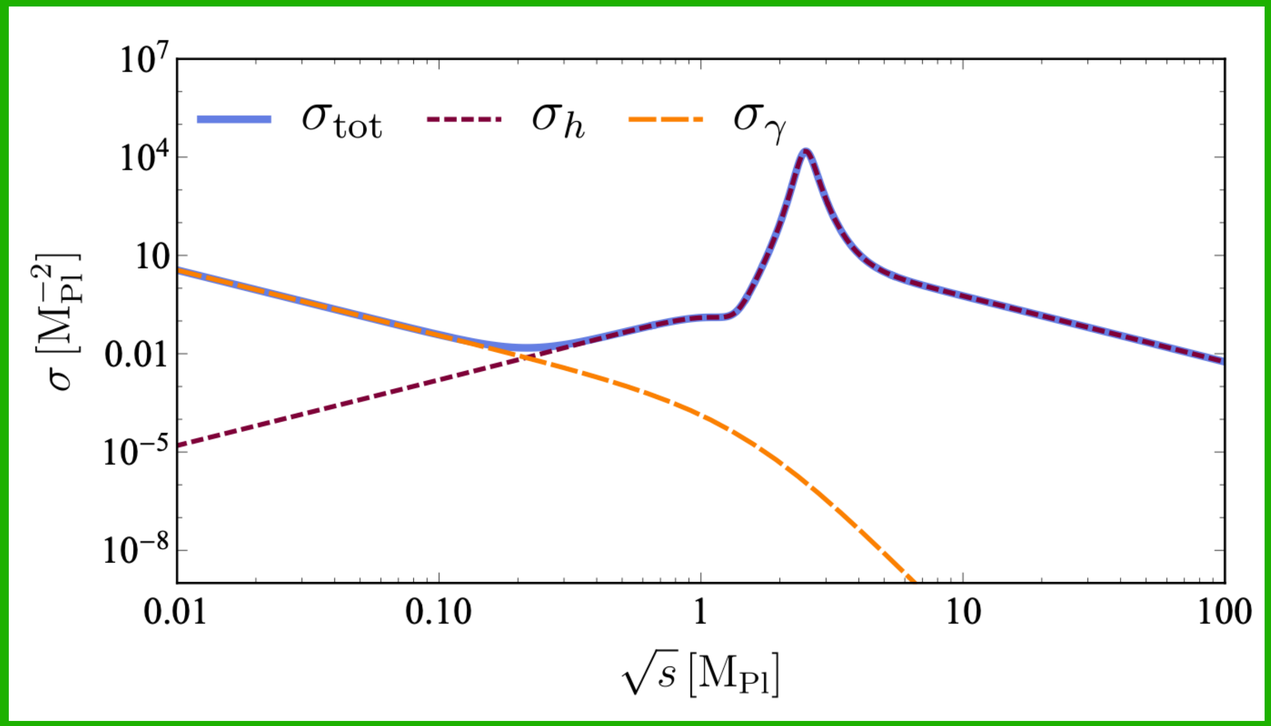

[Pastor-Gutiérrez, Pawlowski, Reichert, Ruisi '24]

The ASQG landscape

- ASQG landscape = *complete* set of all admissible IR endpoints of RG flow

Basile, Platania

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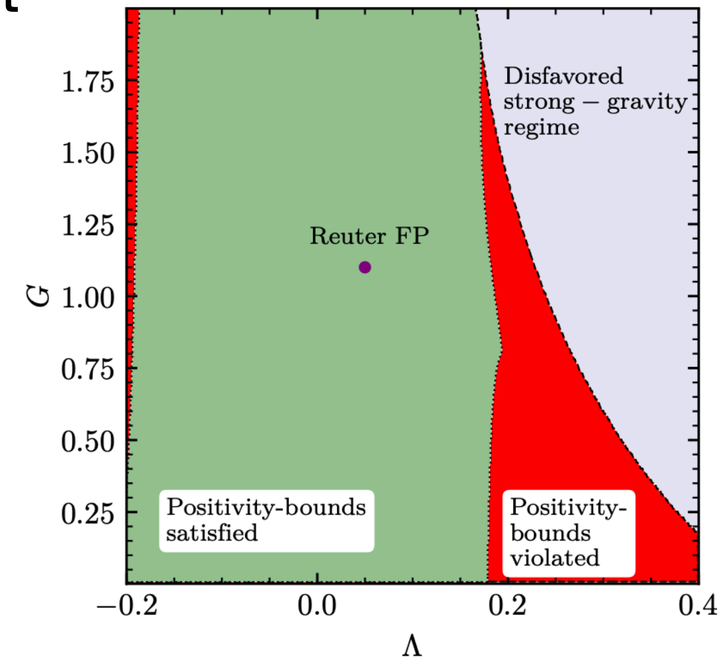

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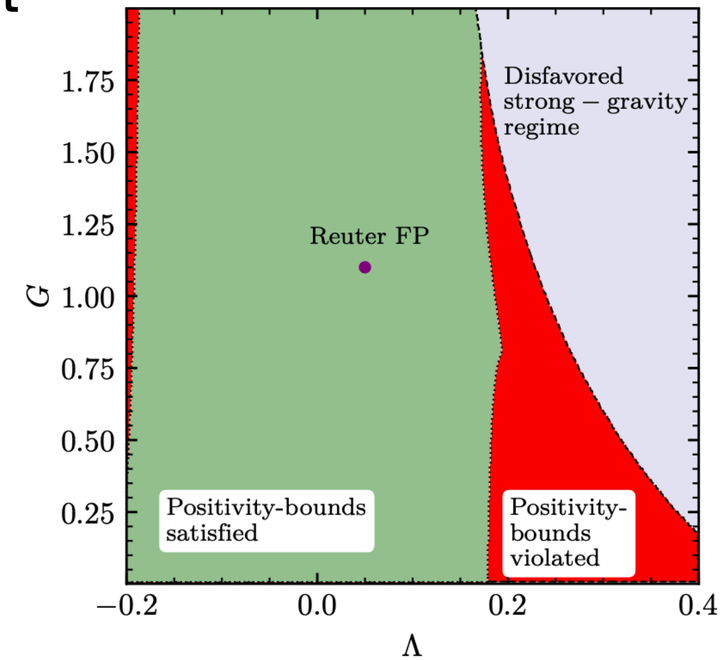

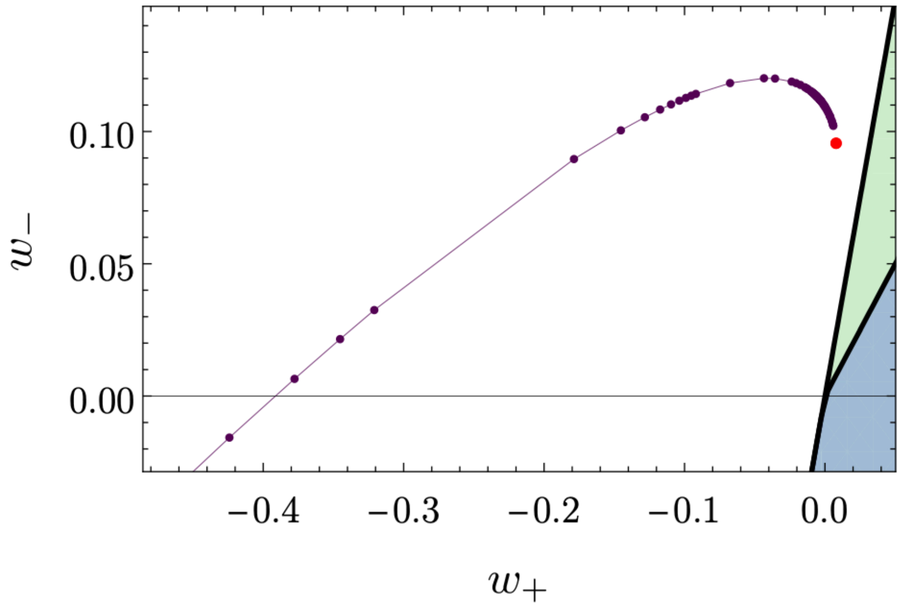

[BK, Platania '24]

Quantum EoMs

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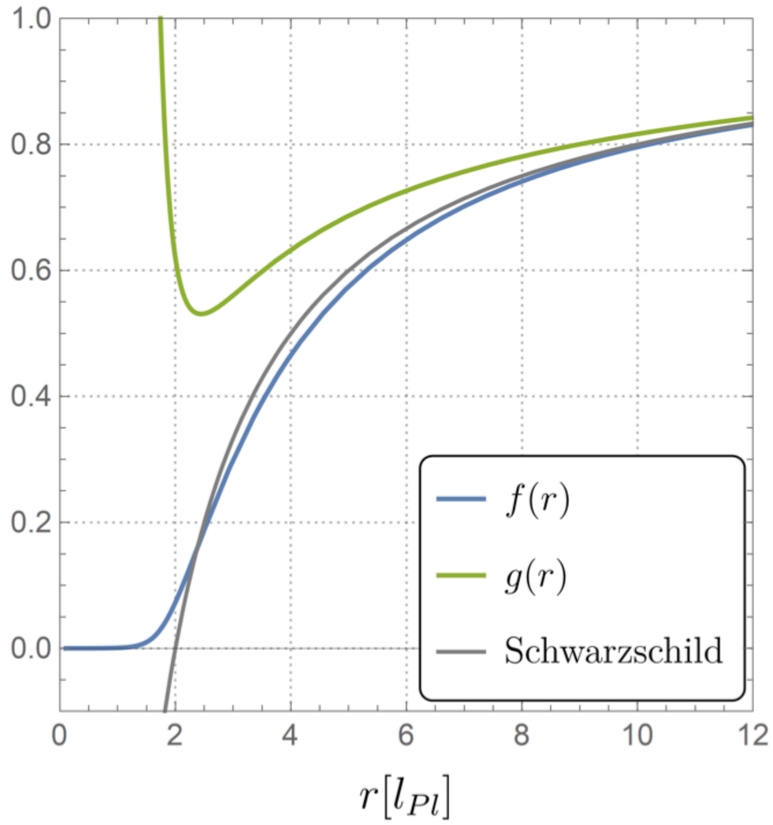

[Pawlowski, Tränkle '23]

The Ugly

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…or: the BIG opportunities

The Ugly

- mathematically rigorous treatment of RG flow

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- (no) strings attached? swampland constraints, black hole physics, topology change, …

ASQG on math

- mathematically rigorous definition of flow

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- could the conformal bootstrap be of any help?

ASQG meets the swampland

Basile, Platania, BK, Schiffer
Eichhorn, Hebecker, Pawlowski, Walcher

- swampland conjectures: delineate non-gravitational EFTs that can be UV-completed by gravity from those that cannot

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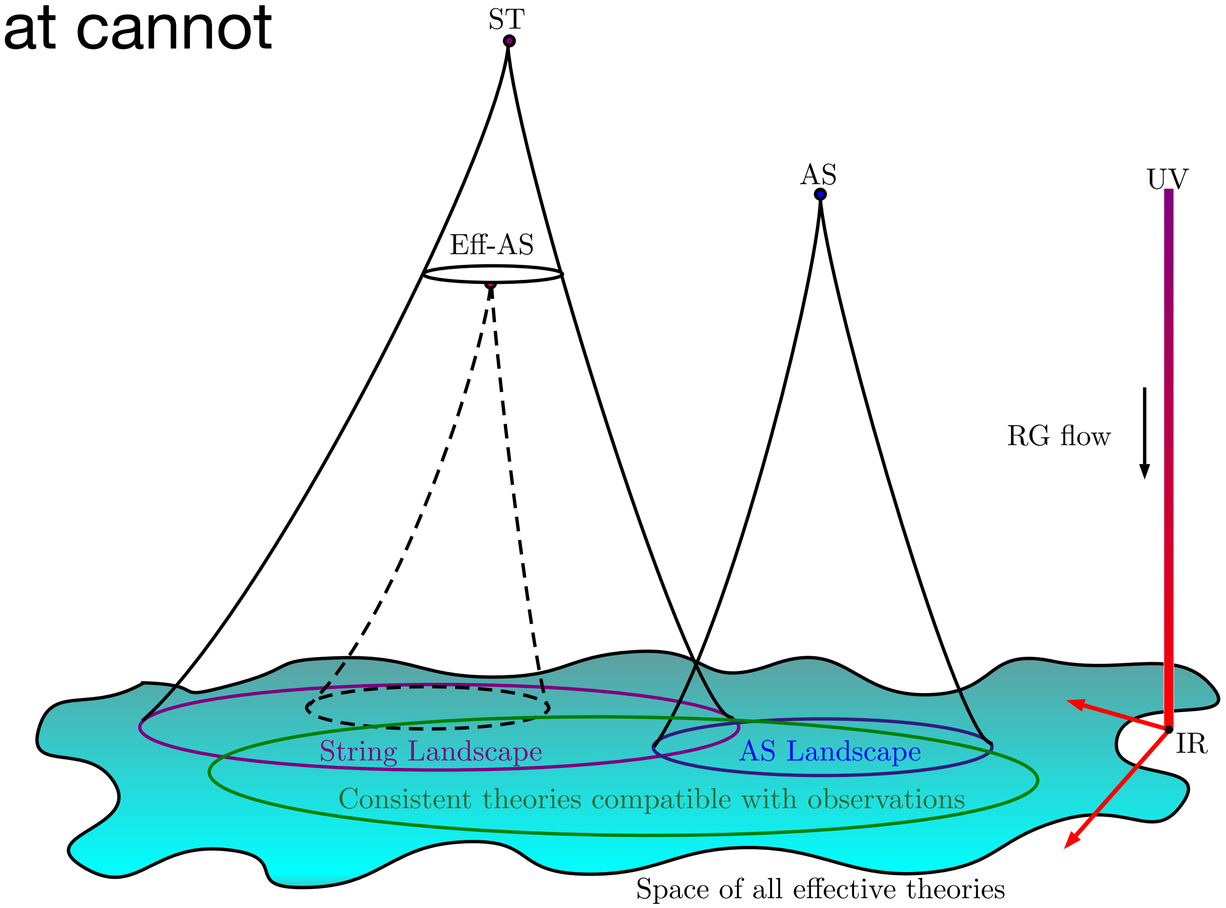

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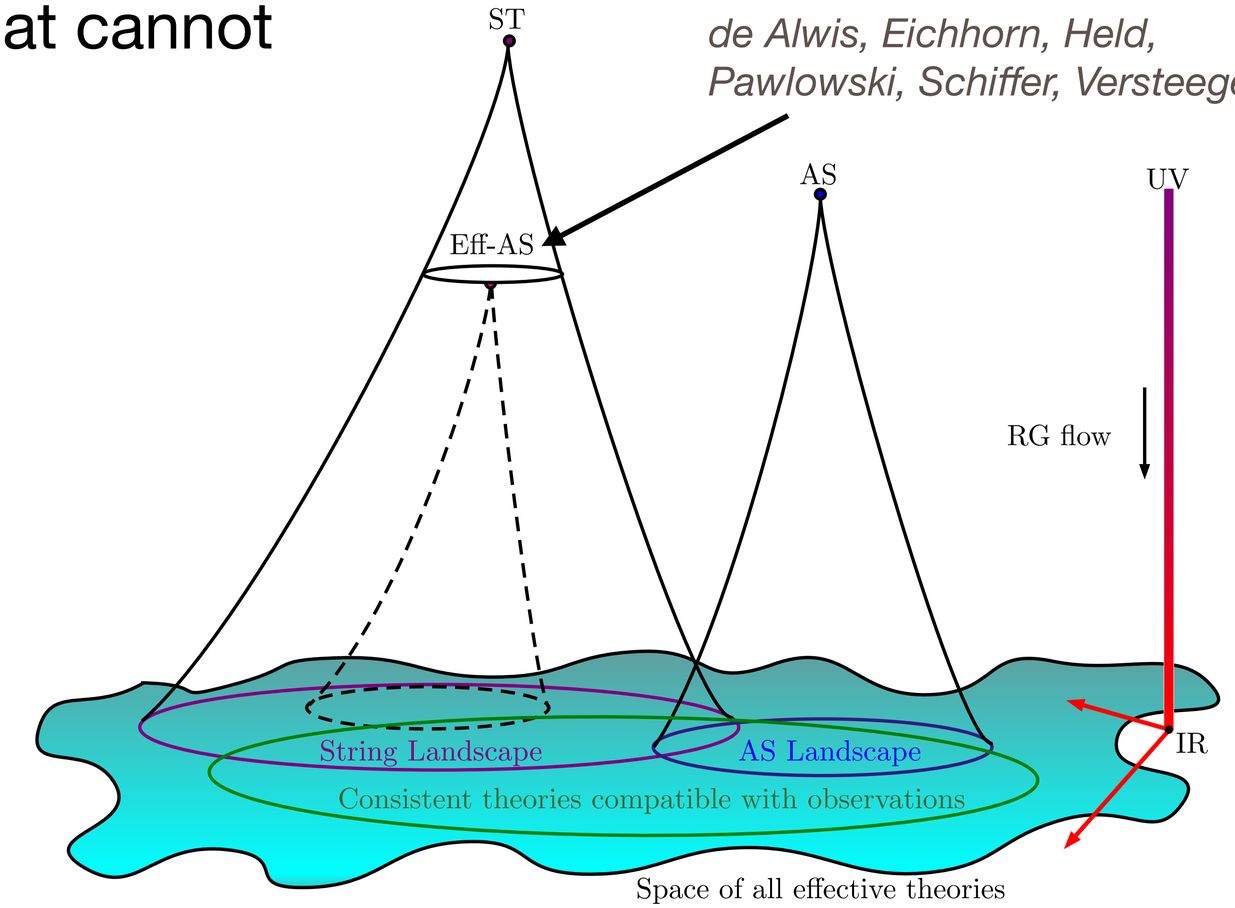

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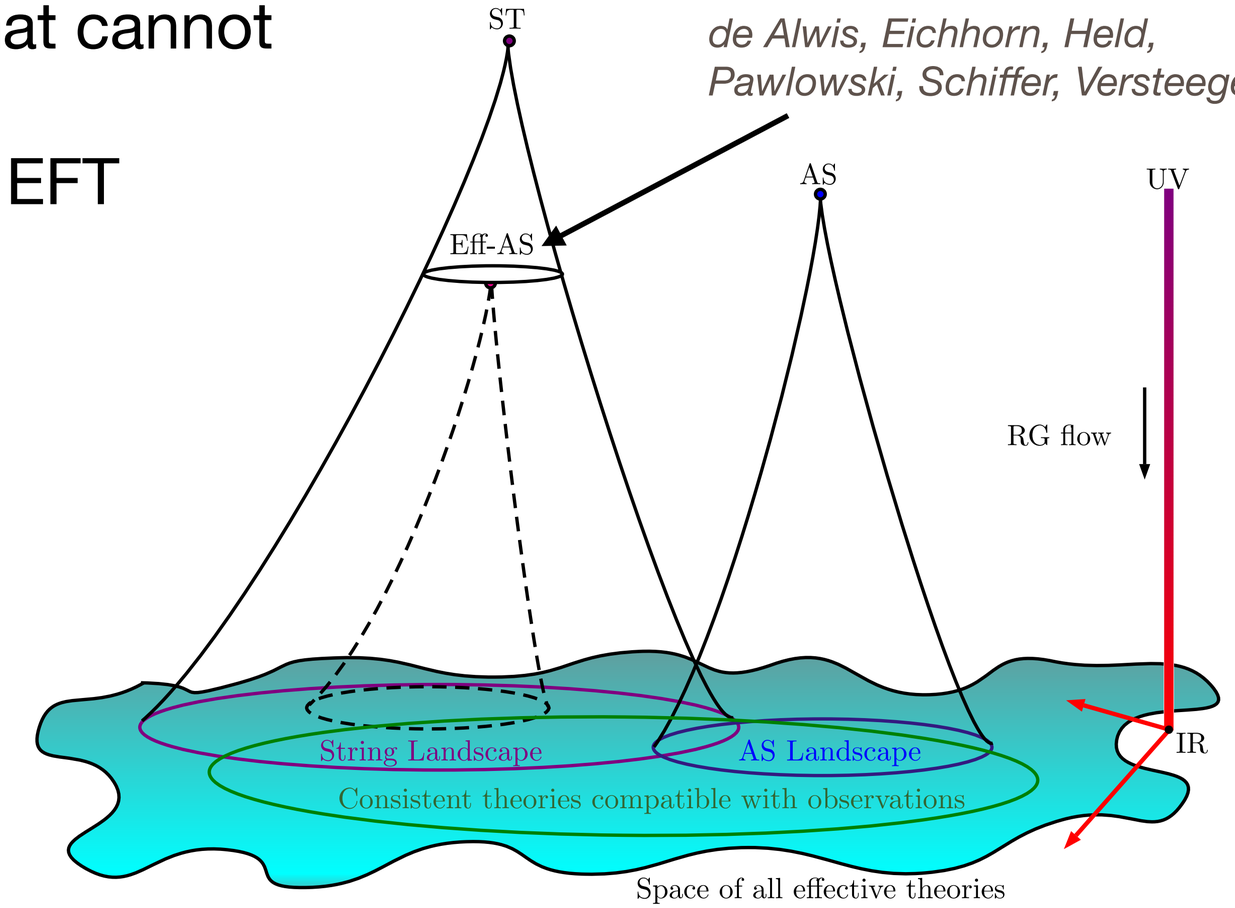
de Alwis, Eichhorn, Held, Pawlowski, Schiffer, Versteegen



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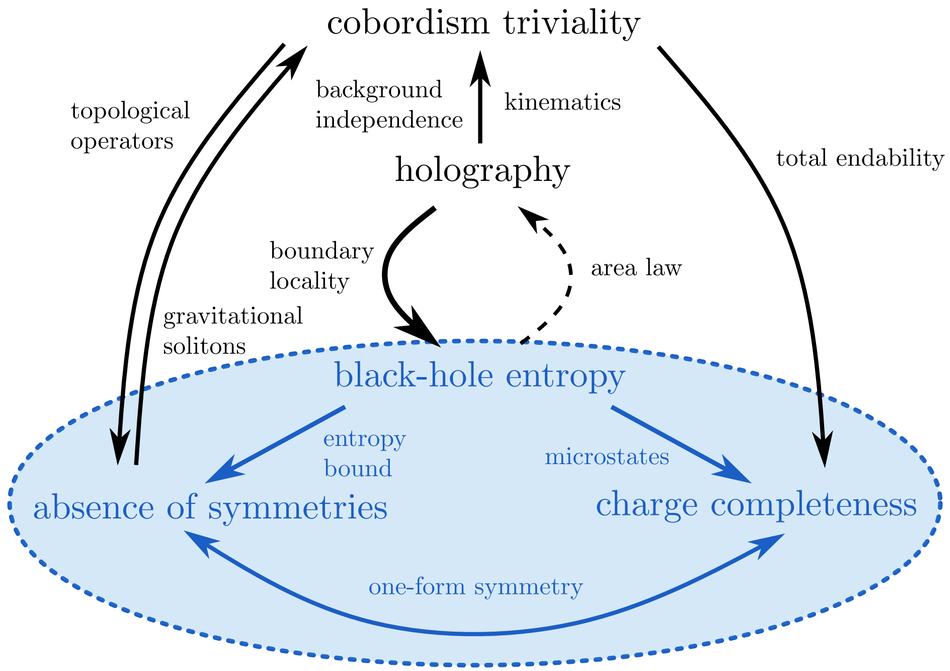

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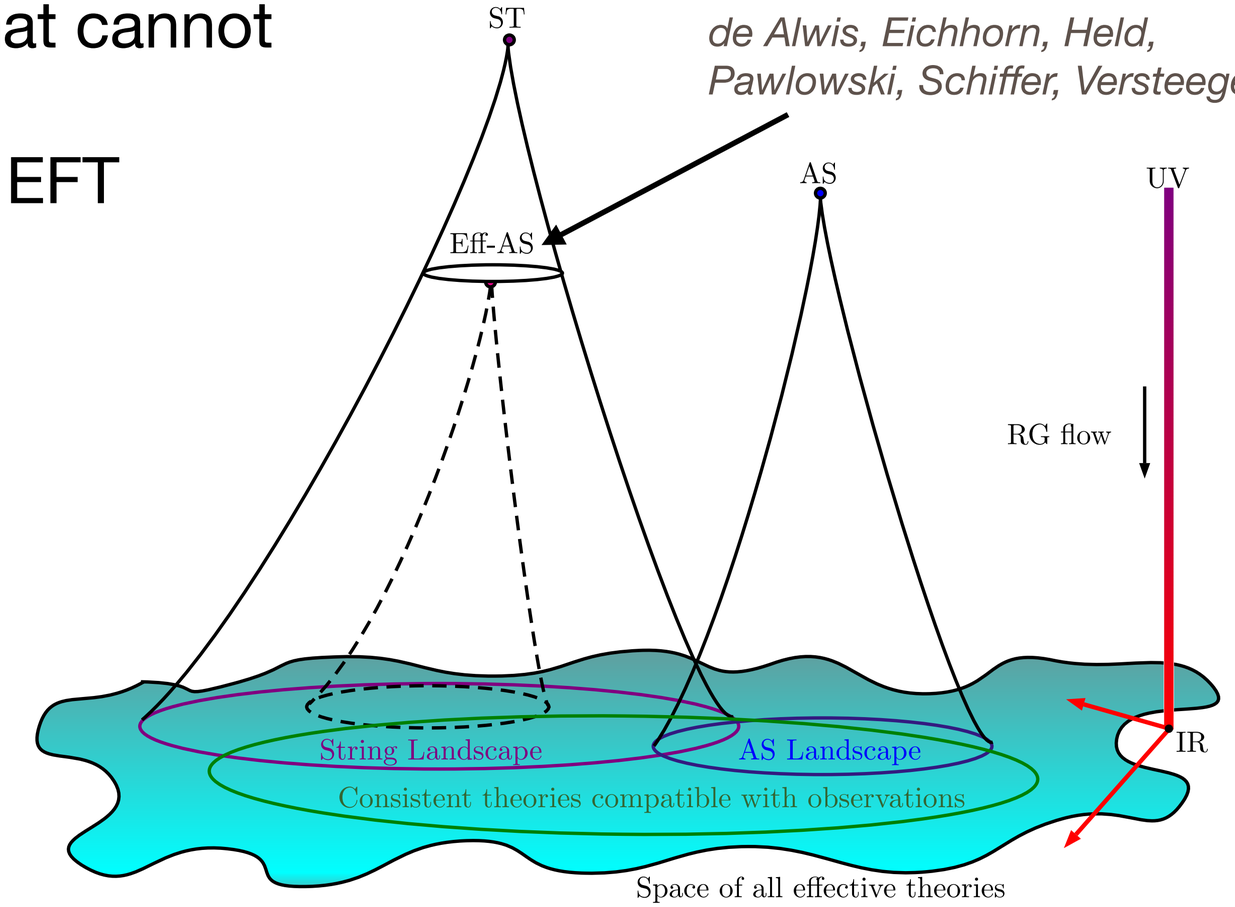

[Basile, BK, Platania, Schiffer '25]

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…or: an unsolicited rant

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- real progress comes through pain and interaction with other communities