Title: Asymptotic safety of gravity and matter

Date: Nov 23, 2017 02:30 PM

URL: http://pirsa.org/17110042

Abstract: <p>Compatibility of asymptotic safety with UV-completions of matter theories may constrain the underlying microscopic dynamics of quantum gravity. Within truncated RG-flows, a weak-gravity bound originates from the loss of quantum scale-invariance in the matter system. Further constraints could arise when linking Planck-scale to electroweak-scale dynamics. Within the constrained region, gravitationally induced scale-invariance could UV-complete the Standard Model, and moreover explain free parameters such as fermion masses and gauge couplings.</p>

Asymptotic safety of gravity and matter

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1711.02949 (Astrid Eichhorn, AH & Christof Wetterich)
1707.01107, to appear in PLB (Astrid Eichhorn & AH)
PRD 96 (2017), 086025 (Astrid Eichhorn & AH)
PRD 94 (2016), 104027 (Astrid Eichhorn, AH & Jan M Pawlowski)

Quantum Gravity Seminar, Perimeter Institute for Theoretical Physics
November 23rd 2017

classical General Relativity

$$\underbrace{G_{\mu\nu}}_{} = \underbrace{8\pi G_N T_{\mu\nu}}_{}$$

spacetime & matter

tells matter how to move | tells spacetime how to curve

? **quantum** General Relativity ?

$$\underbrace{G_{\mu\nu}} = \underbrace{8\pi G_N T_{\mu\nu}}$$

asymptotic safety of
quantum gravity
under the impact of matter fluctuations

&

asymptotic safety of
matter
induced by spacetime fluctuations

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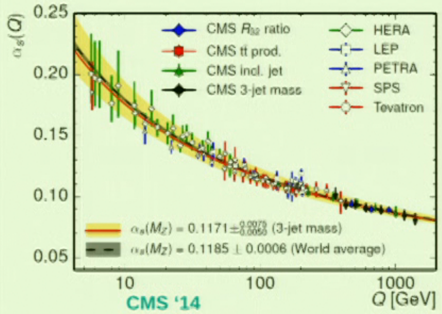
1. Asymptotic safety and gravity

1

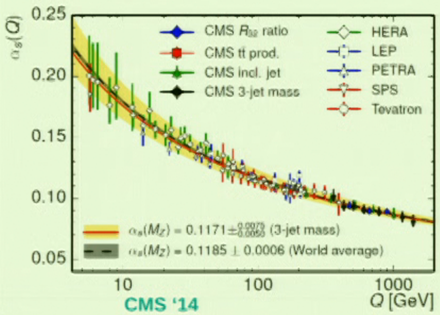
Scales in fundamental physics



CMS '14

- Standard Model: describes the forces of nature as quantized gauge theories
- Renormalization Group running (quantum fluctuations) describes scale-dependence
- perturbative renormalizability as a guiding principle

Scales in fundamental physics



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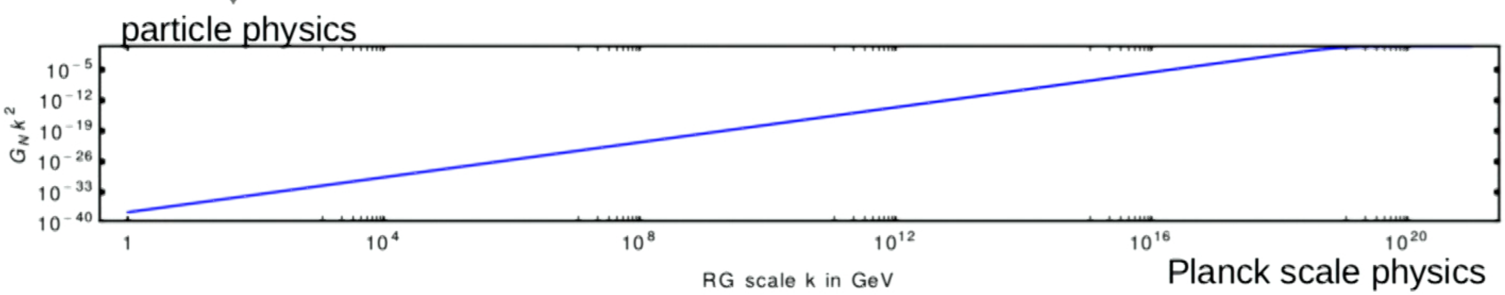
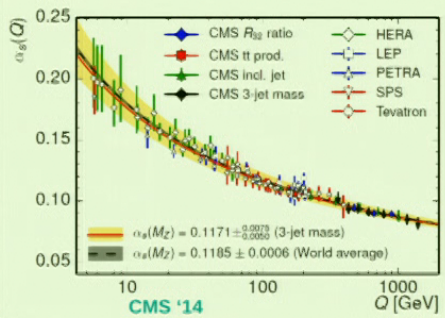


2

Scales in fundamental physics



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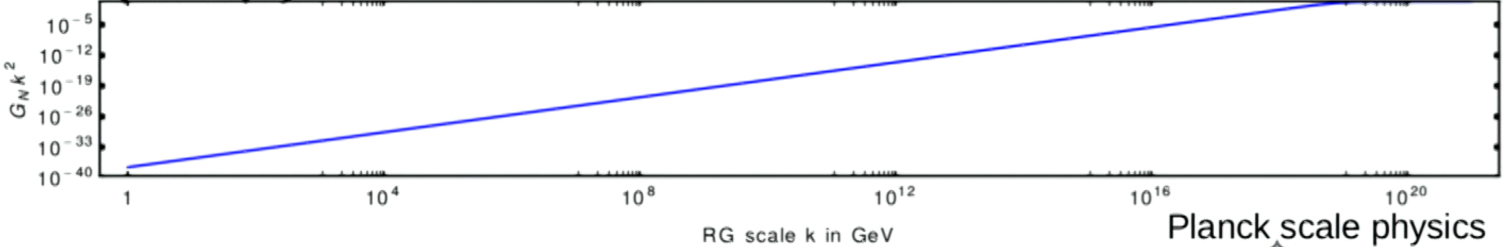
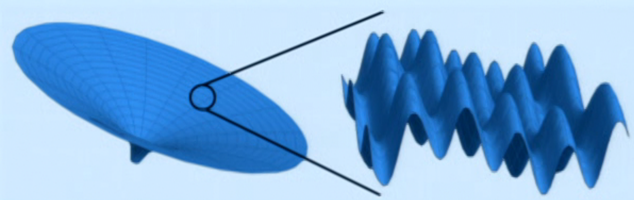
particle physics



Planck scale physics

- crucial at scales where Newton constant $\bar{G}_N \sim 1$
- task: quantized description of spacetime
- perturbatively non-renormalizable $[\bar{G}_N] = -2$

G. 't Hooft and M. J. G. Veltman, '74
S. Deser and P. van Nieuwenhuizen, '74
M. H. Goroff and A. Sagnotti, '81



2

Quantum field theory of the metric

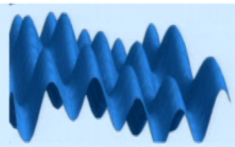
To Do:

- General relativity is a **perturbatively non-renormalizable** quantum field theory.
- Can it still be quantized as a **non-perturbatively renormalizable** quantum field theory, by weighing classical scaling against quantum fluctuations?

$$[\bar{G}_N] = -2$$

Canonical dimension

&



Quantum fluctuations

=

quantum scale-invariance

3

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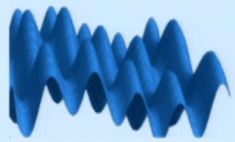

Quantum fluctuations

= **quantum scale-invariance**

$$\int \mathcal{D}g_{\mu\nu} \exp\left[-S_{\text{microscopic}}\right]$$

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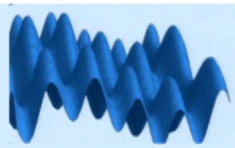

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path-integral for gravity

euclidean

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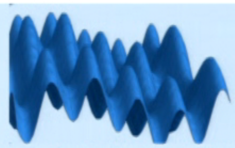

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$$S = \frac{-1}{16\pi\bar{G}_N}\int d^4x\,\sqrt{g}\left[R - 2\bar{\Lambda}\right]?$$

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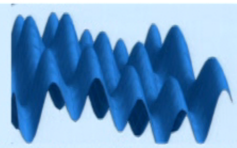

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path-integral for gravity

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quantum fluctuations generate all terms allowed by symmetry

infinite dimensional **theory space**

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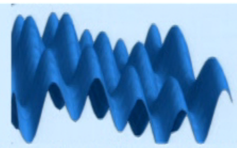

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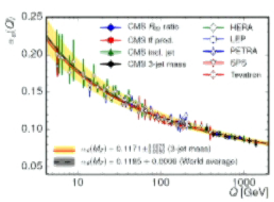
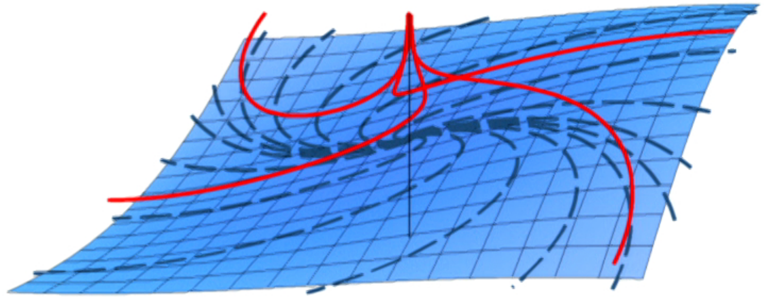


Asymptotic freedom: perturbative renormalizability as a guiding principle

Asymptotic safety conjecture

Weinberg '76



- existence of a UV fixed point for metric field theory (**fundamental theory**)

$$\beta_{\lambda_i} = 0 \quad \forall\, \lambda_i$$

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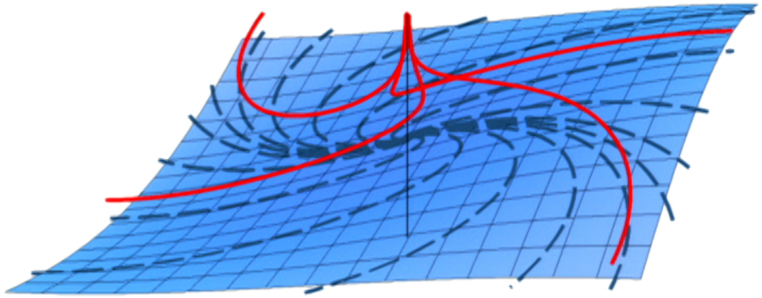

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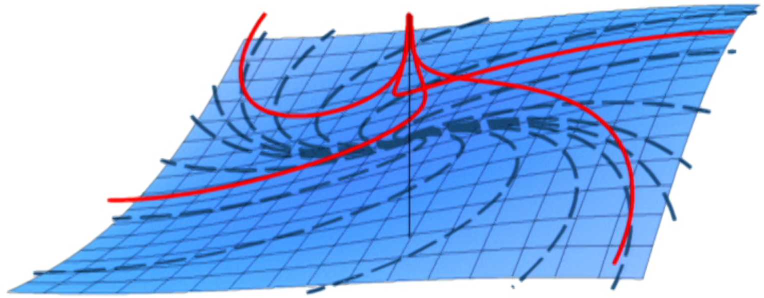
- finite number of UV-attractive directions (**predictivity**)

$$\theta_k = -\left[\mathrm{ev}\left(\frac{\partial \beta_{\lambda_i}}{\partial \lambda_j}\right)\right]_k > 0$$

Asymptotic safety conjecture

Weinberg '76



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- **UV-attractive** (relevant) direction: needs to be fixed by experiment $\theta_i > 0$
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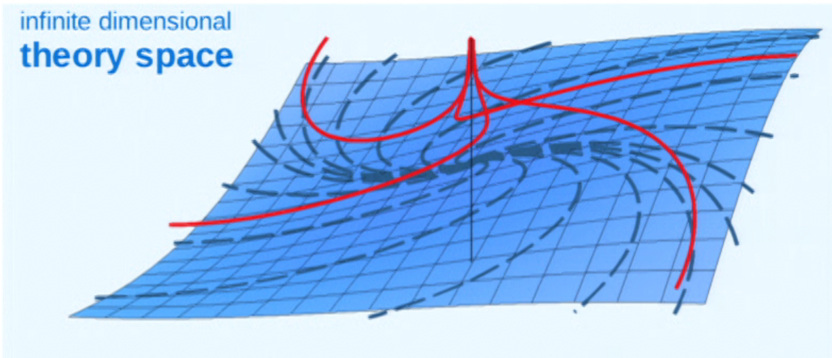
Asymptotic safety conjecture

Weinberg '76



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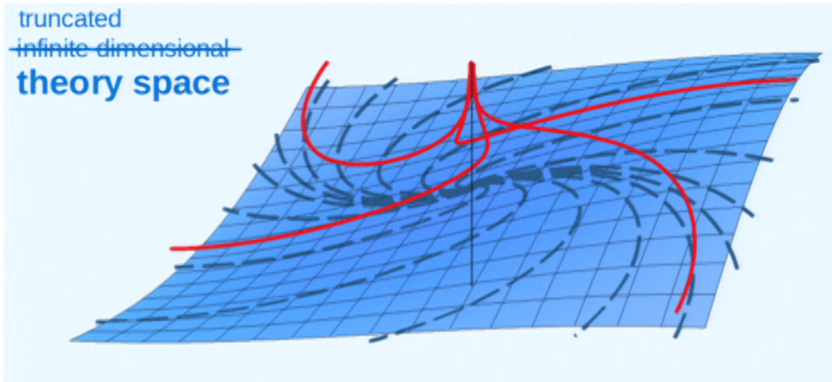
4

Asymptotic safety conjecture

Weinberg '76



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Search for fixed points by use of **truncations** of the functional Renormalization Group

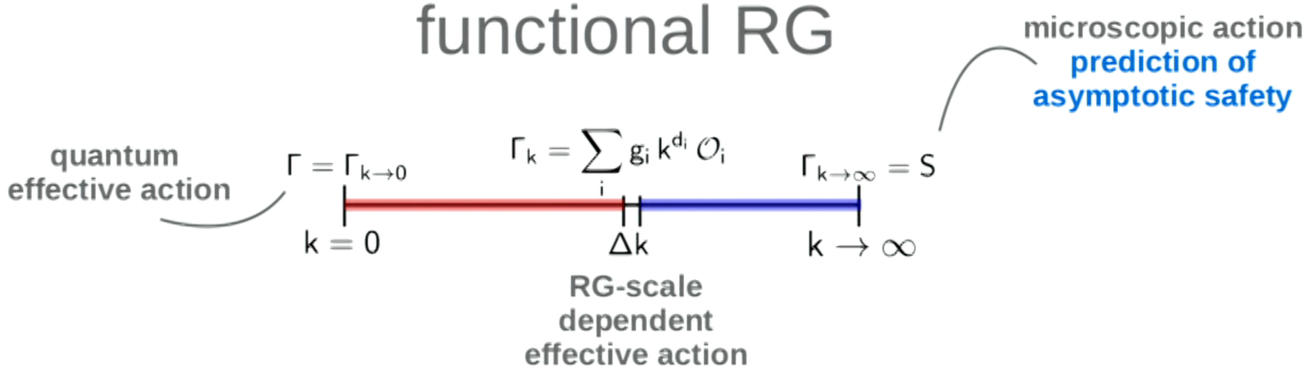
Wetterich '93

truncated ~~infinite dimensional~~ **theory space**

$$S = \frac{-1}{16\pi \bar{G}_N} \int d^4x \sqrt{g} \Big[R - 2\bar{\Lambda} + \cancel{+ \bar{a}R^2 + \bar{b}R_{\mu\nu}R^{\mu\nu} + \ldots \text{ all terms allowed by symmetry}} \Big]$$

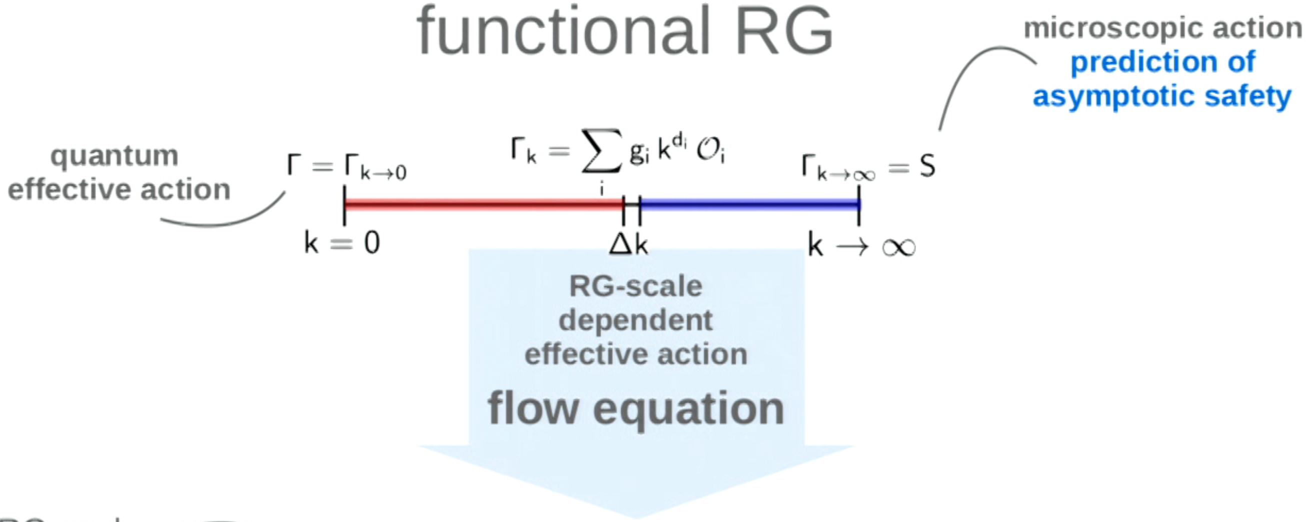
4

functional RG



5

functional RG



RG-scale dependent effective action

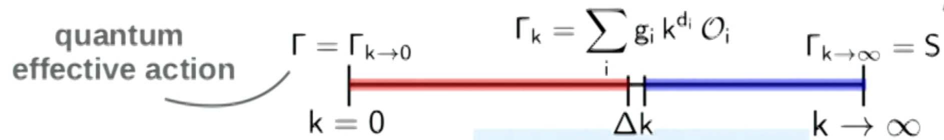
$$k\partial_k \Gamma_k = \frac{1}{2}\mathrm{Tr}\left(\Gamma_k^{(2)}[\Phi] + R_k\right)^{-1} k\partial_k R_k$$

Wetterich '93

5

functional RG

microscopic action
prediction of asymptotic safety



RG-scale dependent effective action

flow equation

RG-scale dependent effective action

$$k\partial_k \Gamma_k = \frac{1}{2}\mathrm{Tr}\left(\Gamma_k^{(2)}[\Phi] + R_k\right)^{-1} k\partial_k R_k$$

Wetterich '93

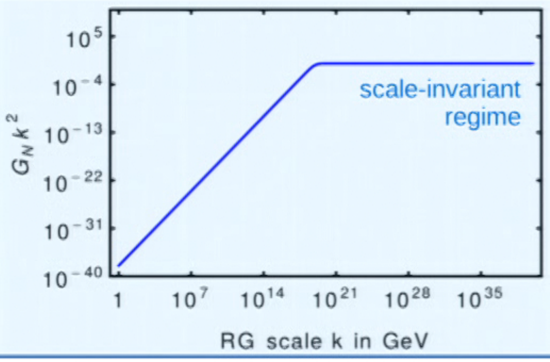
allows for **projections** on beta functions

$$k\partial_k \Gamma_k = \sum_i (\beta_i + d_i\, g_i)\; k^{d_i} \mathcal{O}_i \xrightarrow{\text{projection}} \beta_i$$

Asymptotic safety: truncations

Weinberg '76
Reuter '96

1-dimensional truncation



$$S_{\text{trunc.}} = -\frac{1}{16\pi \bar{G}_N}\int d^4x\,\sqrt{g}\,R$$

$$\beta_{G_N} = \underbrace{2\,G_N}_{\text{dimensional}} - \underbrace{\frac{23}{3\pi}G_N^2}_{\text{quantum}} + \dots$$

Codello, Percacci, Rahmede '08

work with dimensionless couplings $G_N = \bar{G}_N\,k^2$

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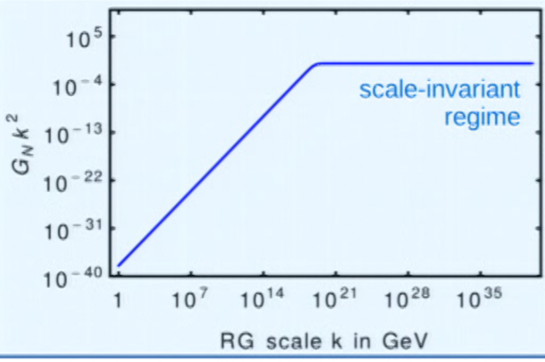

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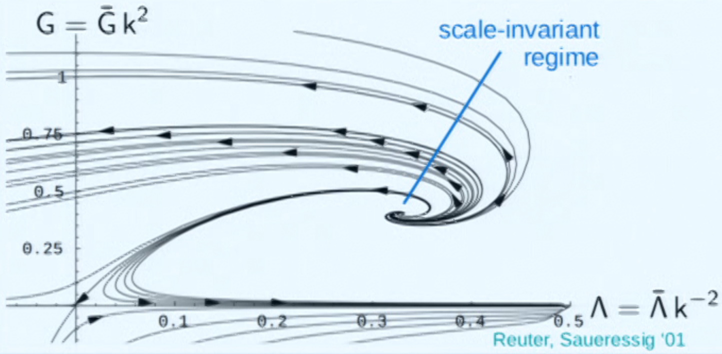
2-dimensional truncation



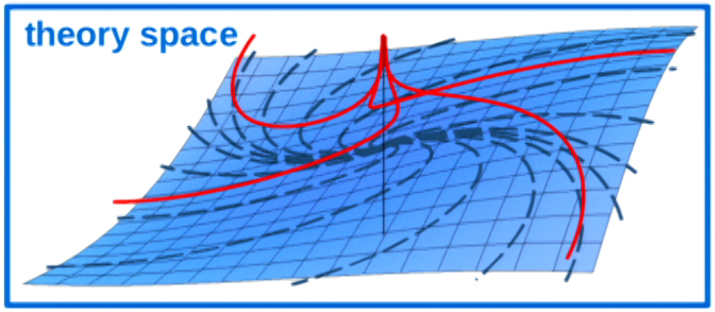
Reuter, Saueressig '01

$$S_{\text{trunc.}} = -\frac{1}{16\pi\bar{G}}\int d^4x\,\sqrt{g}\,\left[R - 2\bar{\Lambda}\right]$$

two UV-attractive directions

Asymptotic safety: truncations

Weinberg '76
Reuter '96



$f(R)$

$\vdots$

$\lambda_4 R^4$

$\lambda_3 R^3$ $\quad \sigma_k C_{\mu\nu}^{\rho\sigma} C_{\rho\sigma}^{\kappa\lambda} C_{\kappa\lambda}^{\mu\nu}$ $\quad$ + more

$\lambda_2 R^2$ $\quad b\, R_{\mu\nu} R^{\mu\nu}$

$\frac{R}{G_N}$

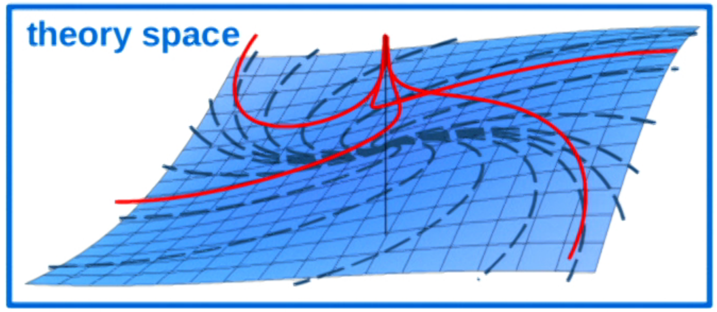
$\frac{\Lambda}{G_N}$

Reuter '96
D. Becker and M. Reuter '14, 1404.4537
T. Denz, J. M. Pawlowski and M. Reichert '16, 1612.07315
B. Knorr '17, 1710.07055
J. Biemans, A. Platania, F. Saueressig '16, 1609.04813
B. Knorr, S. Lippholdt '17, 1707.01397

7

Asymptotic safety: truncations

Weinberg '76
Reuter '96



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H. Gies, B. Knorr, S. Lippoldt and F. Saueressig '16, 1601.01800

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Reuter, Lauscher '02, 0205062

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D. Benedetti, P. F. Machado and F. Saueressig '09, 0901.2984
N. Christiansen '16, 1612.06223

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Reuter '96
D. Becker and M. Reuter '14, 1404.4537
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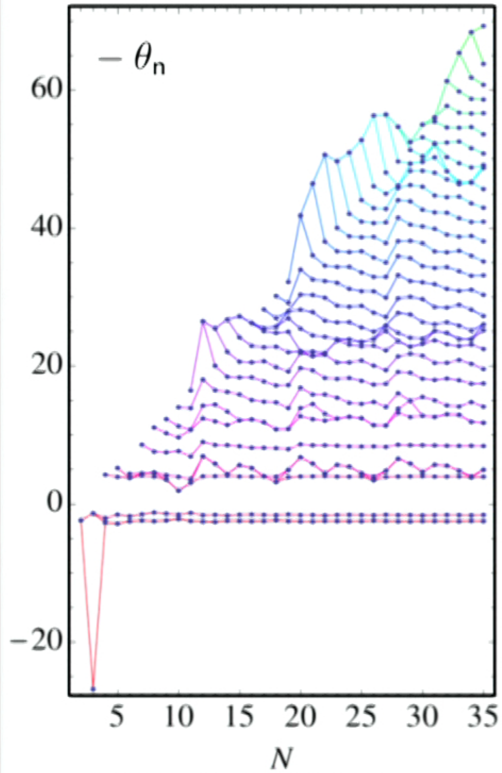

K. Falls, D. F. Litim, K. Nikolakopoulos and C. Rahmede '14, 1410.4815

Codello, Percacci, Rahmede '07, '08
Machado, Saueressig '07
K. Falls, D. F. Litim, K. Nikolakopoulos and C. Rahmede '13, 1301.4191
...

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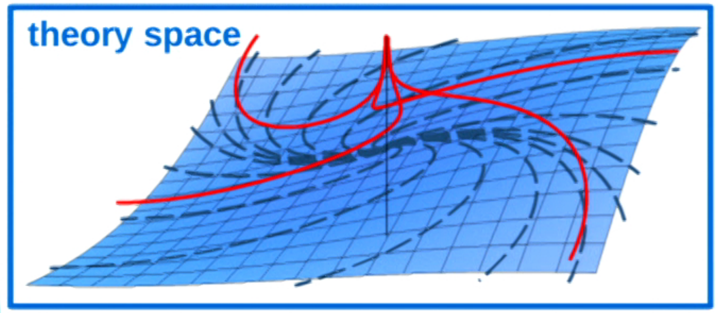

H. Gies, B. Knorr, S. Lippoldt and F. Saueressig '16, 1601.01800

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Asymptotic safety: truncations

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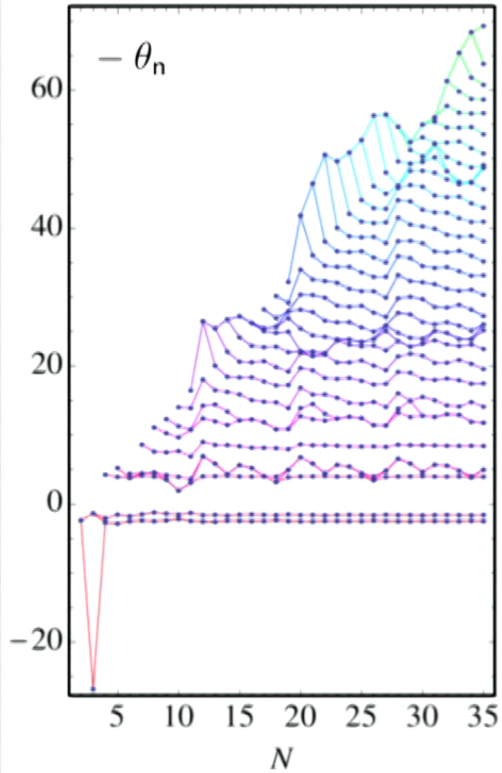

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J. Biemans, A. Platania, F. Saueressig '16, 1609.04813
B. Knorr, S. Lippholdt '17, 1707.01397

observe powerful guiding principle

near-canonical scaling
& apparent convergence

H. Gies, B. Knorr, S. Lippoldt and F. Saueressig '16, 1601.01800

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D. Benedetti, P. F. Machado and F. Saueressig '09, 0901.2984
N. Christiansen '16, 1612.06223

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Asymptotic safety: truncations

Weinberg '76
Reuter '96

evidence for
asymptotic safety in pure gravity

$$\underbrace{G_{\mu\nu}}_{} = \underbrace{8\pi G_N T_{\mu\nu}}_{}$$

asymptotic safety of
quantum gravity
under the impact of matter fluctuations

&

asymptotic safety of
matter
induced by spacetime fluctuations

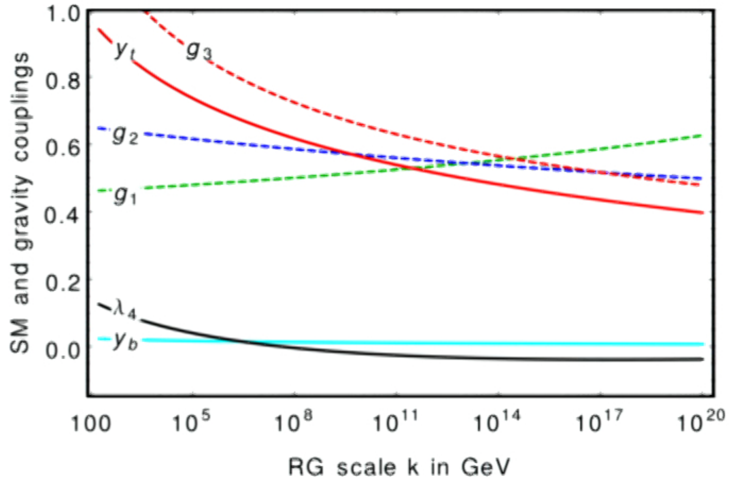
2. Asymptotic safety and matter

Asymptotic safety from a SM perspective

RG equations $\beta_c^{SM} \sim (d-4)\,c \pm \#\,c^3 + \text{h.o.} \quad \forall\ c \in \{g_1, g_2, g_3, y_t, y_b\}$

marginal canonical dimension

Quantum fluctuations



cf., Buttazzo et.Al. '13, 1307.3536

Standard Model
as an effective field theory could be
valid up to the Planck scale

Asymptotic safety from a SM perspective

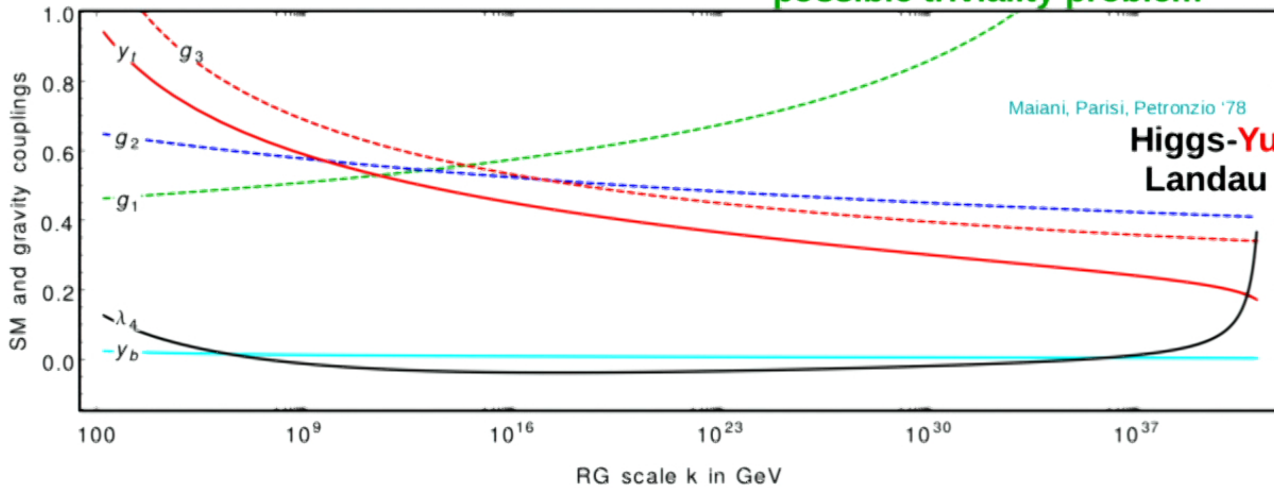
RG equations $\beta_c^{SM} \sim (d-4)\,c \pm \#\,c^3 + \text{h.o.} \quad \forall\; c \in \{g_1, g_2, g_3, y_t, y_b\}$

marginal canonical dimension

Quantum fluctuations

Gell-Mann, Low '54
Gockeler, Horsley, Linke, Rakow, Schoierholz, Stuben '98
...

U(1) Landau pole possible triviality problem



Maiani, Parisi, Petronzio '78

Higgs-Yukawa Landau pole

9

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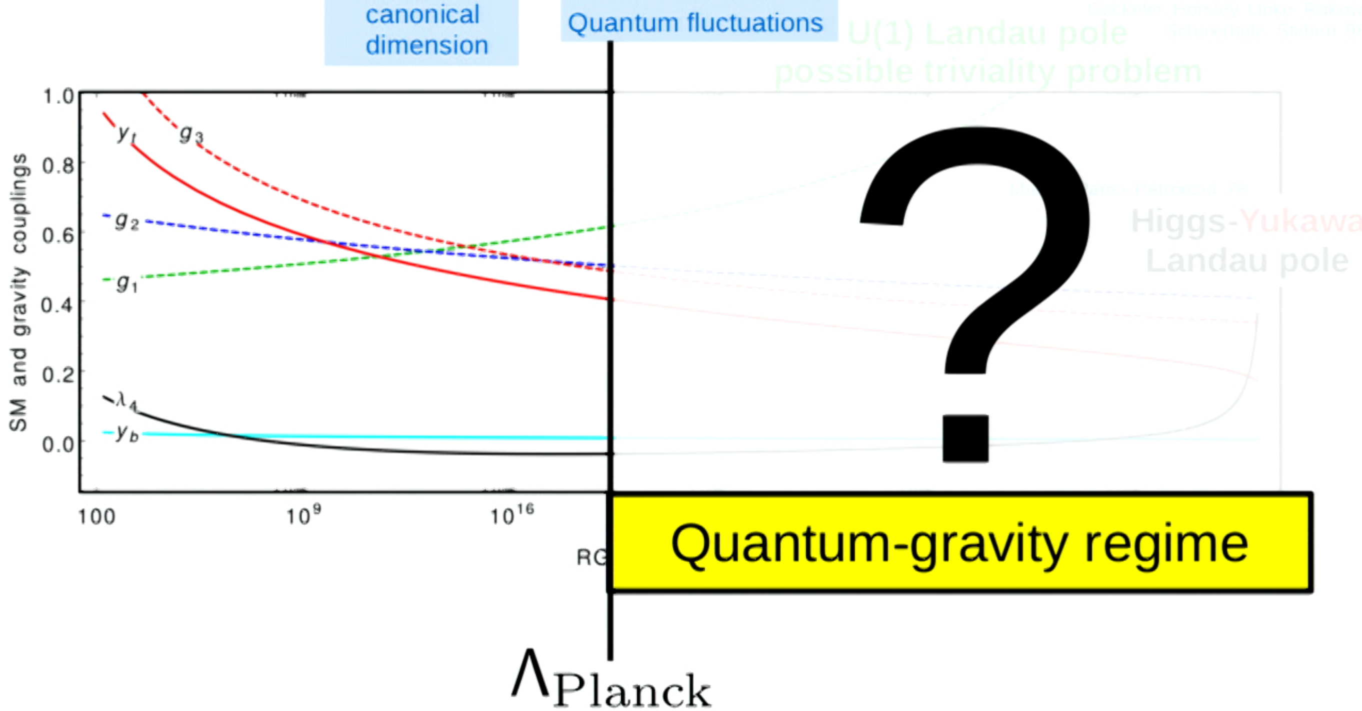


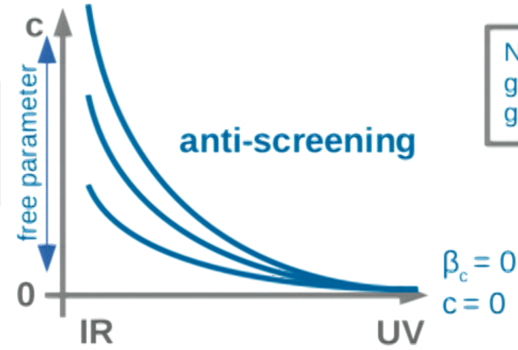
9

Asymptotic **freedom**

Scale invariance at a **Gaussian** fixed point ensures a **free** (perturbatively renormalizable) UV theory.
No predictive power.

$$\beta_c^{SM} \sim -\#\, c^3 + \text{h.o.}$$

anti-screening quantum fluctuations



in the SM

Non-Abelian gauge couplings g_2 and g_3

10

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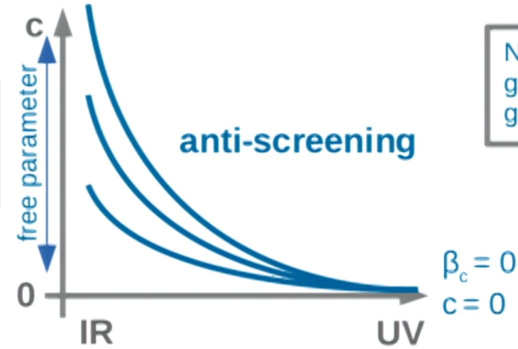


in the SM

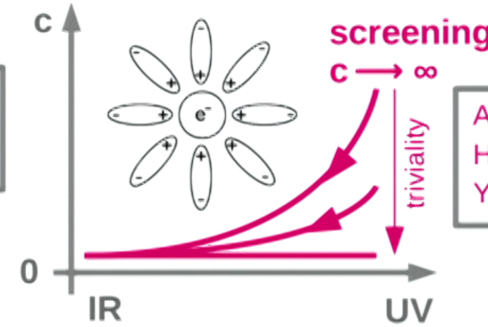
Non-Abelian gauge couplings g_2 and g_3

Triviality

Landau divergence at finite scales indicates a **triviality problem**.
UV-scaling **predicts vanishing coupling**.

$$\beta_c^{SM} \sim +\#\, c^3 + \text{h.o.}$$

screening quantum fluctuations



in the SM

Abelian gauge g_1
Higgs quartic λ_H
Yukawa couplings y_i

10

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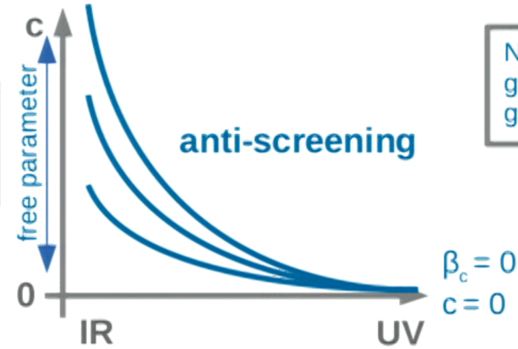

in the SM

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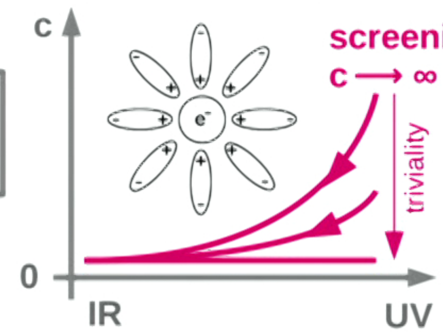


in the SM

Abelian gauge g_1
Higgs quartic λ_H
Yukawa couplings y_i

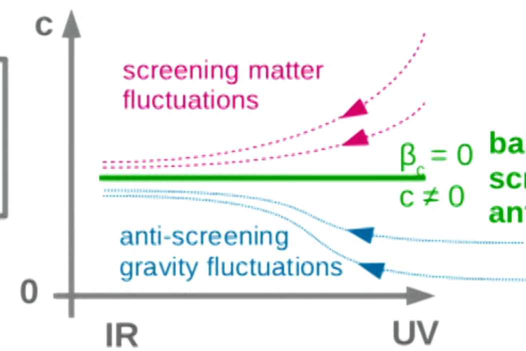
Asymptotic **safety**

Scale invariance at a **non-Gaussian** fixed point ensures a **safe** (non-perturbatively renormalizable) UV theory.
Fundamental QFT **predicts finite coupling**.

$$\beta_c^{SM} \sim -f_c\, c + \#\, c^3 + \text{h.o.}$$

quantum gravity anti-screening

Standard Model quantum fluctuations



balance of screening & anti-screening

10

$$G_{\mu\nu} = 8\pi G_N T_{\mu\nu}$$

asymptotic safety of **spacetime** under the impact of matter fluctuations & asymptotic safety of **matter** induced by spacetime fluctuations

… adding matter to gravity ...

$$\underbrace{G_{\mu\nu}}_{} = \underbrace{8\pi G_N T_{\mu\nu}}_{}$$

asymptotic safety of
spacetime
under the impact of matter fluctuations

&

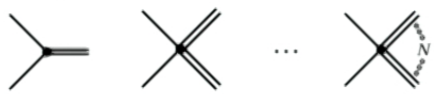
asymptotic safety of
matter
induced by spacetime fluctuations

… adding matter to gravity ...

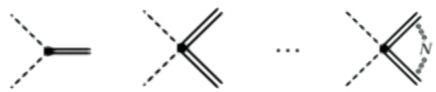
3. Asymptotic safety of gravity and matter

Gravitational induction

$$S_{\psi\mathrm{kin}} = i \int d^4x \sqrt{\det(g)} \left(\bar{\psi}\gamma^{\mu}\nabla_{\mu}\psi\right)$$

$\Longrightarrow$ 

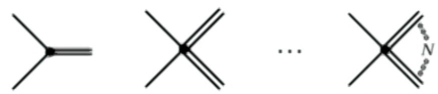
$$S_{\phi\mathrm{kin}} = \frac{1}{2} \int d^4x \sqrt{\det(g)} \left(g^{\mu\nu}\partial_{\mu}\phi\partial_{\nu}\phi\right)$$

$\Longrightarrow$ 

12

Gravitational induction

$$S_{\psi \mathrm{kin}} = i \int d^4x \sqrt{\det(g)}\, \left(\bar{\psi}\gamma^\mu \nabla_\mu \psi\right)$$

$\Longrightarrow$ 

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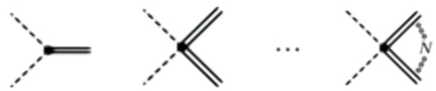
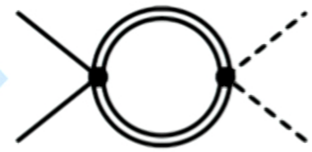
$\Longrightarrow$ 

Gies, Eichhorn '11, 1104.5366
Eichhorn '12, 1204.0965

gravitational induction



$\sim G_N^2$

12

Gravitational induction

$$S_{\psi \mathrm{kin}} = i \int d^4x \sqrt{\det(g)}\, (\bar{\psi}\gamma^\mu \nabla_\mu \psi)$$

$\Longrightarrow$ 

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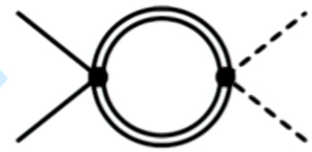
$\Longrightarrow$ 

Gies, Eichhorn '11, 1104.5366
Eichhorn '12, 1204.0965

gravitational induction



$\sim G_N^2$

Eichhorn, Held '17, 1705.02342

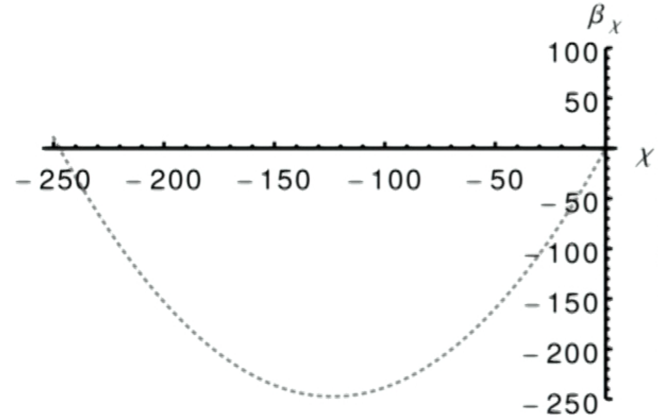
gravity induces all matter interactions invariant under the
maximal global symmetries
of the matter kinetic terms

$$i\chi \int d^4x \sqrt{g} \Big[\left(\bar{\psi}\gamma^\mu \nabla_\nu \psi - (\nabla_\nu \bar{\psi})\gamma^\mu \psi\right) (\partial_\mu \phi \partial^\nu \phi) + \left(\bar{\psi}\gamma^\mu \nabla_\mu \psi - (\nabla_\mu \bar{\psi})\gamma^\mu \psi\right) (\partial_\nu \phi \partial^\nu \phi) \Big]$$

Weak gravity bound

canonical dimension **pure matter**

$$\beta_\chi = 4\chi + \#_\chi \chi^2$$

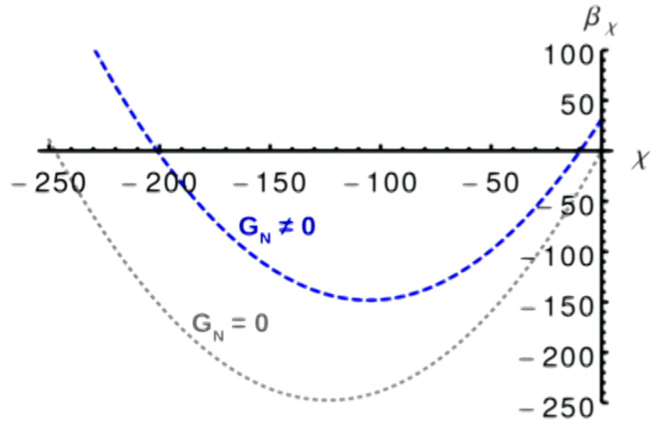


Eichhorn, Held, Pawlowski '16, 1604.02041
Master thesis Held '16

Weak gravity bound

canonical dimension **pure matter** **induced** **mixed**

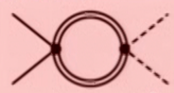
$$\beta_\chi = 4\chi + \#_\chi \chi^2 + \#_{G1} G_N^2 + \#_{G2} G_N \chi$$



Eichhorn, Held, Pawlowski '16, 1604.02041
Master thesis Held '16

Weak gravity bound

canonical dimension | pure matter | induced | mixed



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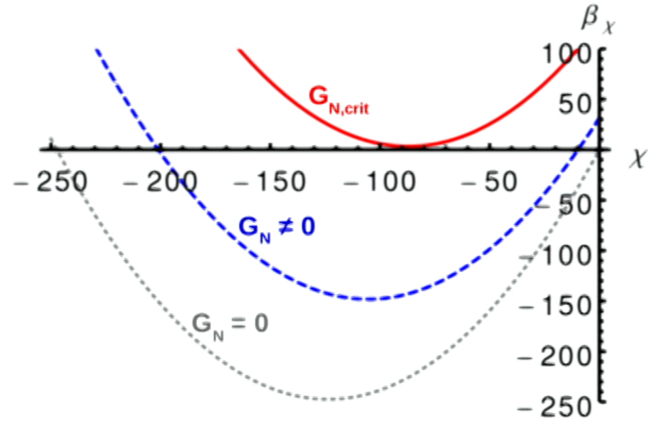


Eichhorn, Held, Pawlowski '16, 1604.02041
Master thesis Held '16

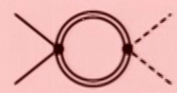
within truncations

Weak gravity bound:

Too strong gravity triggers **new divergences** in the **matter sector**

Weak gravity bound

canonical dimension — pure matter — induced — mixed



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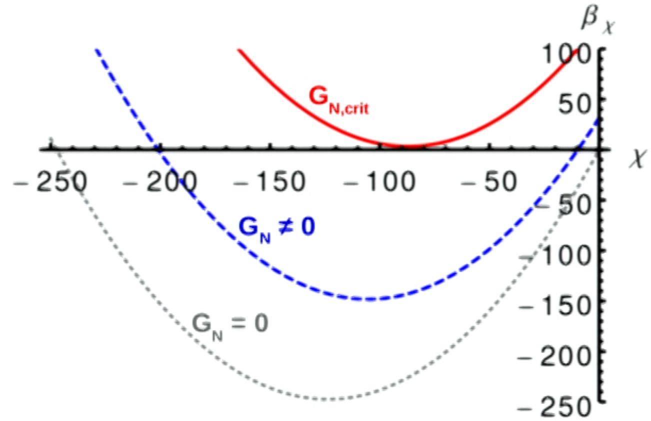

Eichhorn, Held, Pawlowski '16, 1604.02041
Master thesis Held '16

within truncations

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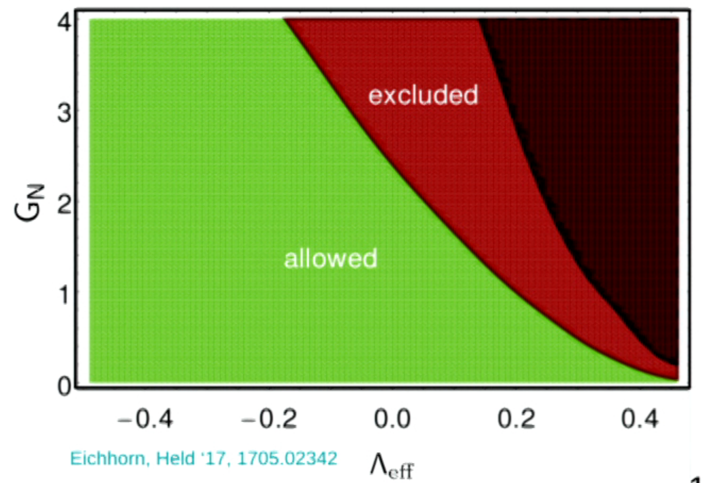
spin-2 mode

$$\left(\Gamma^{(2)}_{k,\,\mathrm{TT}}\right)^{-1} = \frac{32\pi G_N}{p^2 - 2\Lambda}$$

Newton coupling

microscopic cosmological constant

- a large (and negative) **cosmological constant** (and higher curvature couplings) work like an **effective mass**



Eichhorn, Held '17, 1705.02342

13

Weak gravity bound

canonical dimension | pure matter | induced | mixed

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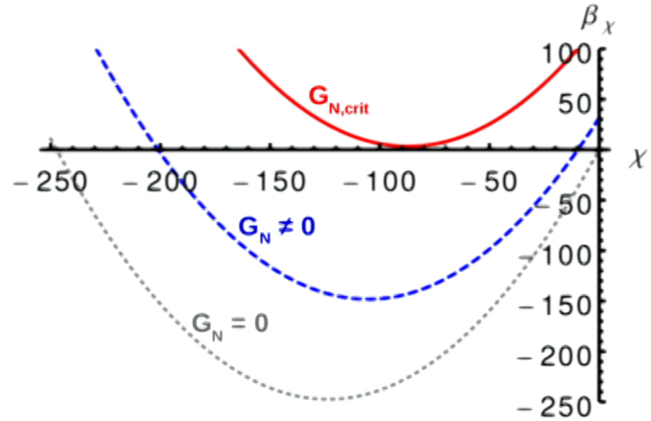

Eichhorn, Held, Pawlowski '16, 1604.02041
Master thesis Held '16

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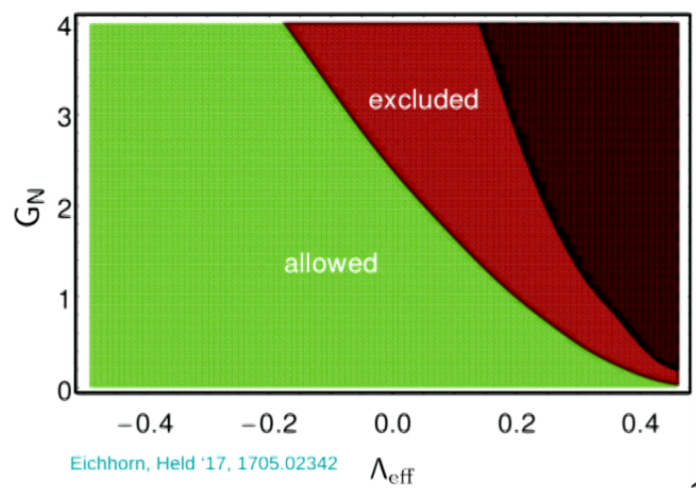
- a large (and negative) **cosmological constant** (and higher curvature couplings) work like an **effective mass**
- remaining question: does adding matter effectively weaken or strengthen gravity?

P. Dona, A. Eichhorn, R. Percacci '13, 1311.2898
J. Meibohm, J. Pawlowski, M. Reichert '15, 1510.07018
J. Biemans, A. Platania, F. Saueressig '17, 1702.06539



Eichhorn, Held '17, 1705.02342

Asymptotic safety of gauge couplings

Asymptotic safety of gauge couplings

$$\beta_\alpha = (\mathcal{N} - \mathcal{N}_c)\,\frac{\alpha^2}{4\pi} - f_\alpha\,(G_N, \Lambda)\,\alpha$$

gauge & matter fluctuations: screening

quantum gravity: anti-screening < 0

Daum, Harst, Reuter '10, JHEP 084
Harst, Reuter '11, JHEP 119
Folkerts, Litim, Pawlowsk '12, Phys.Lett.B 709
Christiansen, Eichhorn '17,Phys.Lett.B 770
Christiansen, Litim, Pawlowski, Reichert '17, 1710.04669
Eichhorn, Versteegen '17, 1709.07252

$$\Longrightarrow \quad \alpha_* = \frac{4\pi\, G_N\, f_\alpha}{\mathcal{N} - \mathcal{N}_c}$$

14

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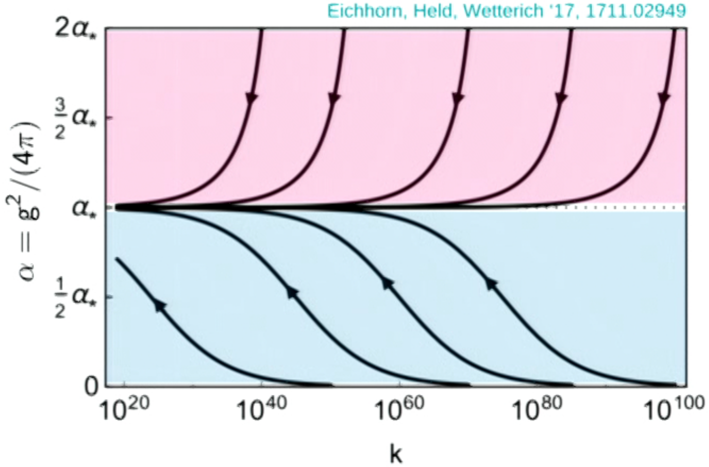

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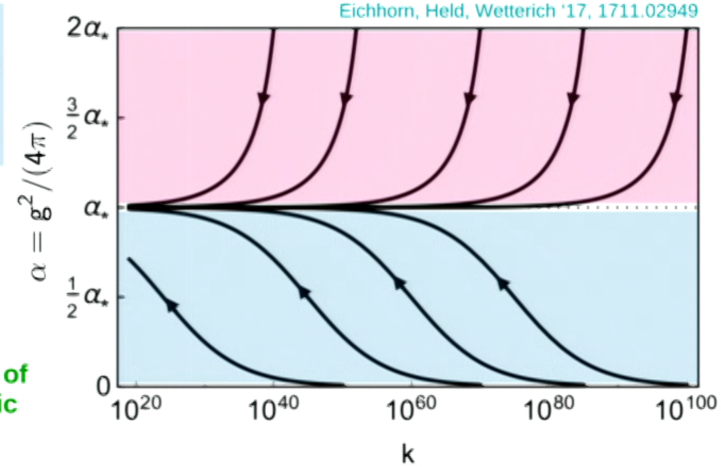
viability of the Standard Model

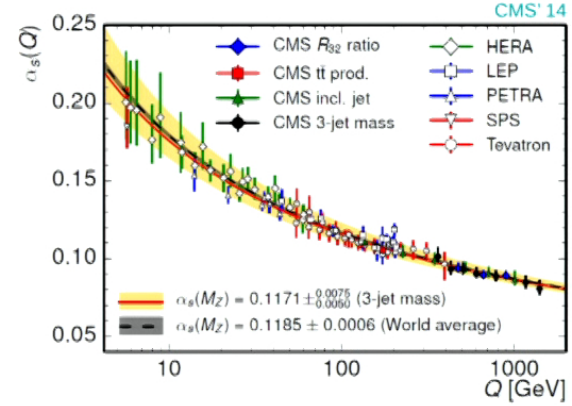
$\mathcal{N} - \mathcal{N}_c = -14$ for SU(3) with SM-matter

speed-up of asymptotic freedom

Eichhorn, Held, Wetterich '17, 1711.02949



CMS' 14



14

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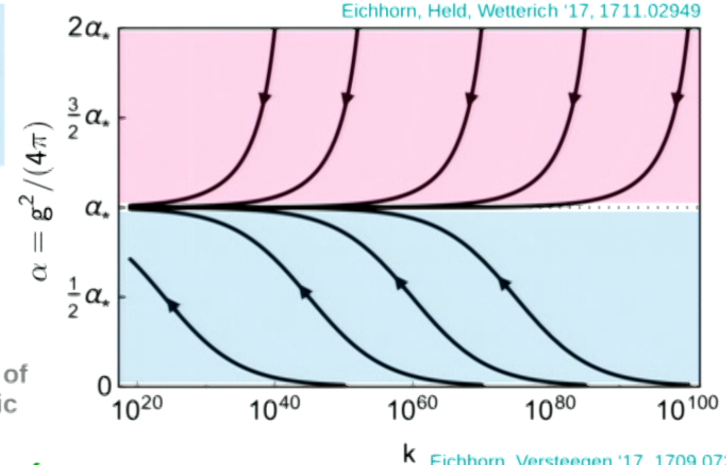
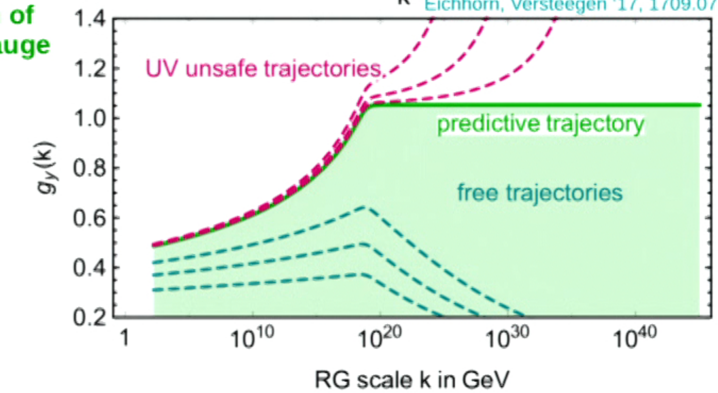
$\mathcal{N} - \mathcal{N}_c = -14$ for SU(3) with SM-matter — speed-up of asymptotic freedom

$\mathcal{N} - \mathcal{N}_c = \frac{41}{5}$ for U(1) with SM-matter — prediction of abelian gauge coupling

Eichhorn, Held, Wetterich '17, 1711.02949



Eichhorn, Versteegen '17, 1709.07252



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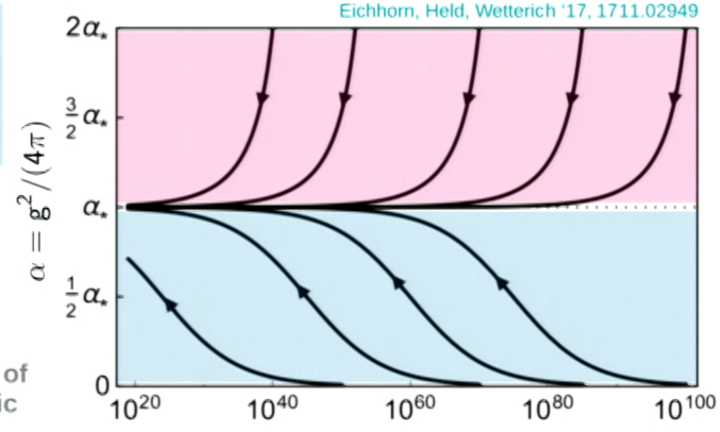
GUT-gravity model building

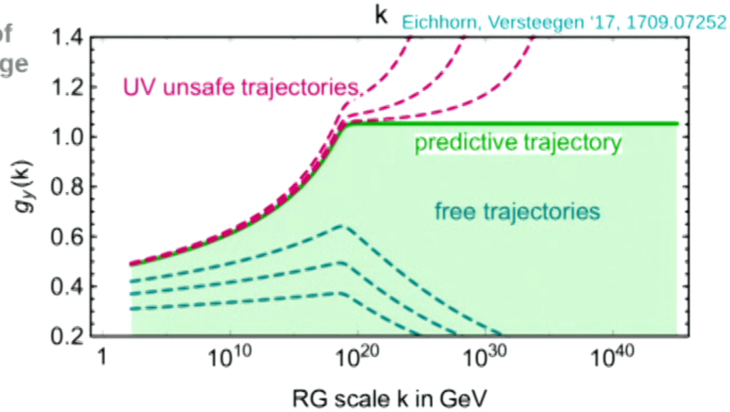
$\mathcal{N} - \mathcal{N}_c = \mathcal{N} - 50$ for SO(10) with three $\mathbf{16}_F$ and $\mathbf{10}_H$

$$\Longrightarrow \quad \alpha_{EM} = \alpha_{EM}(\mathcal{N},\, f_\alpha)$$

Eichhorn, Held, Wetterich '17, 1711.02949



Eichhorn, Versteegen '17, 1709.07252



14

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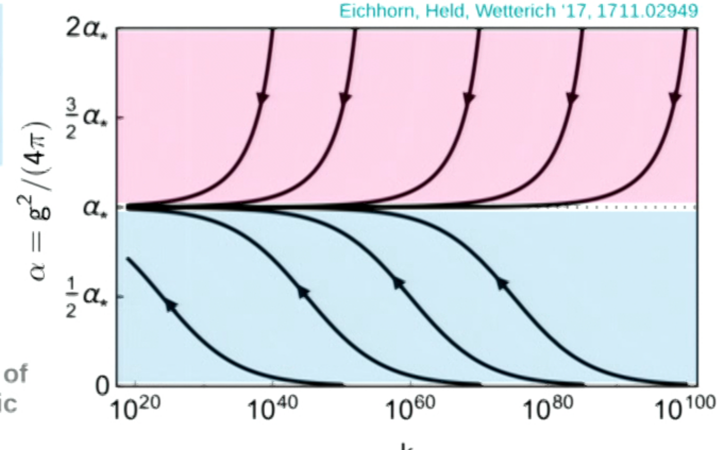
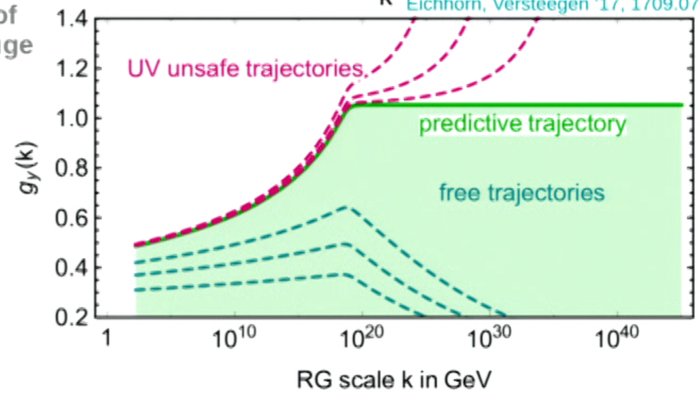
Eichhorn, Held, Wetterich '17, 1711.02949

asymptotic safety offers a mechanism: fixes α_{EM} in terms of quantum gravity (f_α) and matter content $(\mathcal{N})$

Eichhorn, Held, Wetterich '17, 1711.02949



Eichhorn, Versteegen '17, 1709.07252



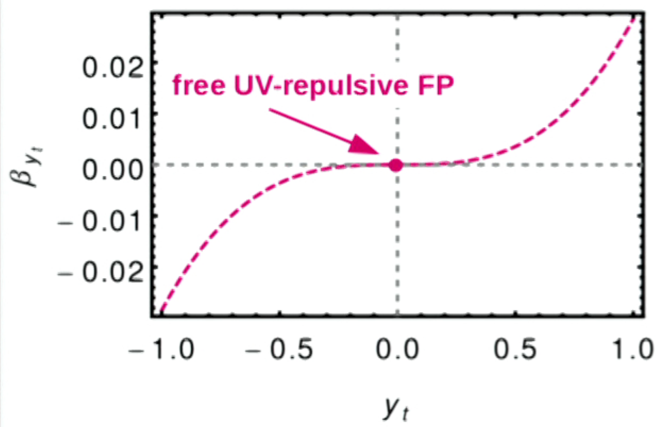
Asymptotic safety of Yukawa couplings

UV-complete SM: triviality problem

SM exhibits **Landau poles in marginally irrelevant** couplings:
$g_1, \ \lambda_4, \ y_t$

Gell-Mann, Low '54
Maiani, Parisi, Petronzio '78
...

$$\beta_{y_t} = \frac{9}{32\pi^2} y_t^3 + (\text{SM-terms})$$

beta-function	running of the coupling
	

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Maiani, Parisi, Petronzio '78
...

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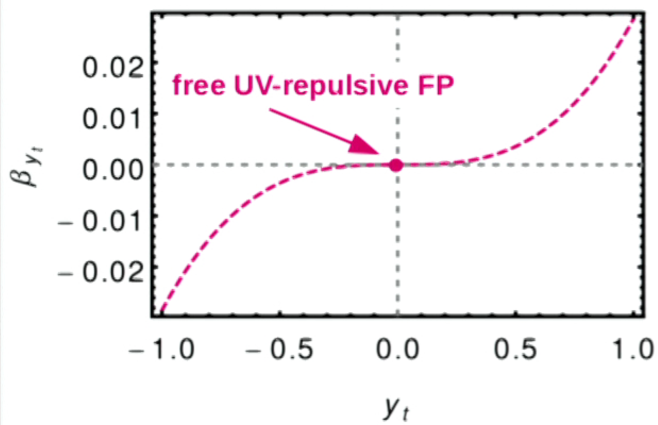
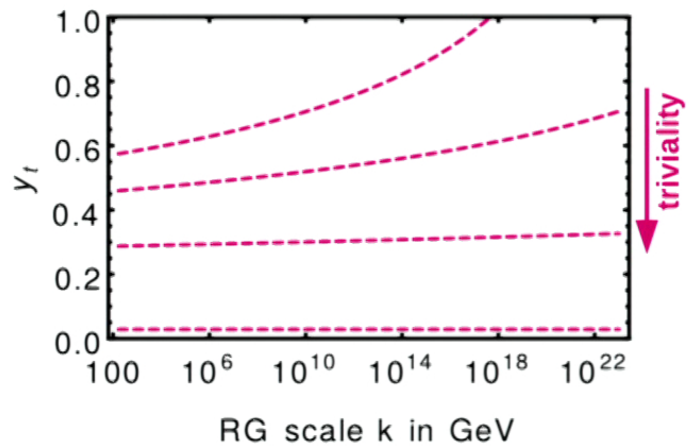
beta-function



running of the coupling



15

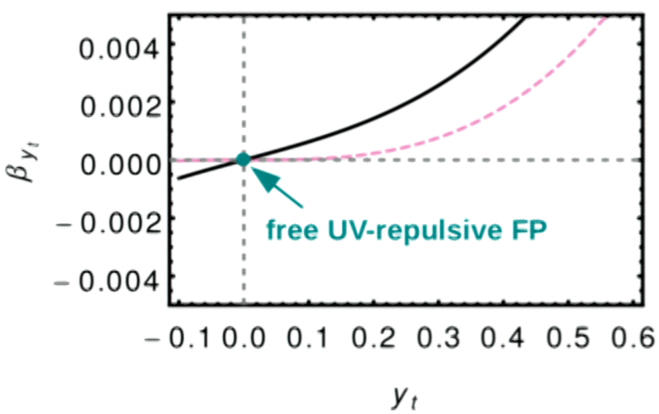
UV-complete SM: predicting the top

quantum gravity

$$\beta_{y_t} = \frac{9}{32\pi^2} y_t^3 + G_N \, y_t \, f_y(\Lambda) + (\text{SM-terms})$$

$f_y(\Lambda) > 0$

screening gravity fluctuations

beta-function	running of the coupling
	

16

UV-complete SM: predicting the top

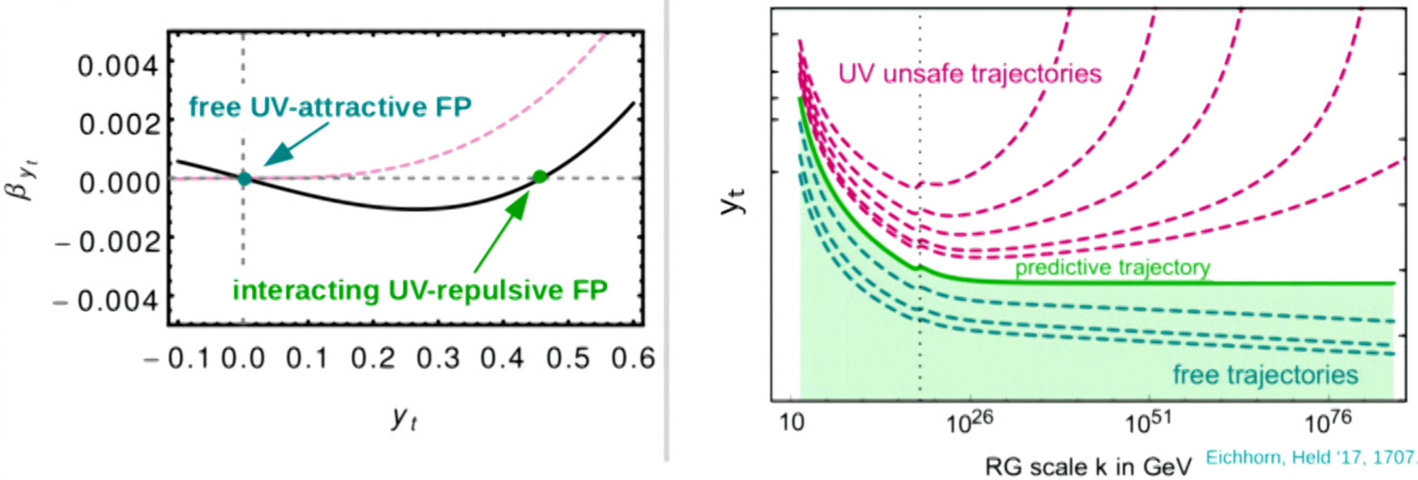
quantum gravity

$$\beta_{y_t} = \frac{9}{32\pi^2} y_t^3 + G_N\, y_t\, f_y(\Lambda) + (\text{SM-terms})$$

$f_y(\Lambda) < 0$

balance of
screening matter and
anti-screening gravity fluctuations

beta-function | running of the coupling



Eichhorn, Held '17, 1707.01107

16

UV-complete SM: predicting the top

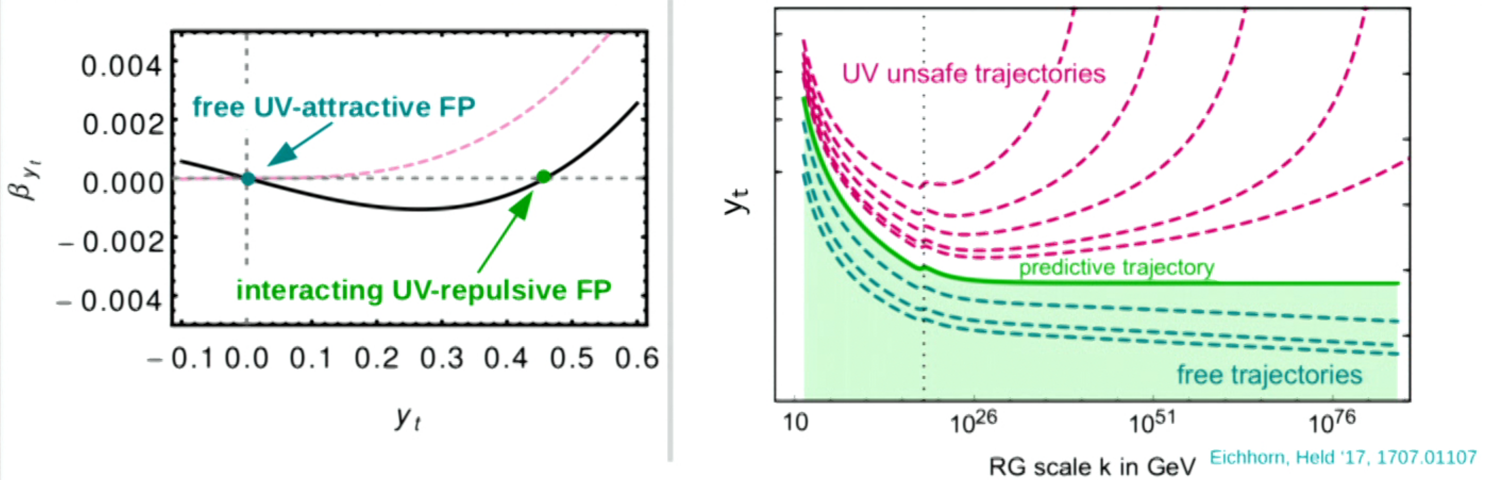
quantum gravity

$$\beta_{y_t} = \frac{9}{32\pi^2} y_t^3 + G_N\, y_t\, f_y(\Lambda) + (\text{SM-terms})$$

$f_y(\Lambda) < 0$

balance of
screening matter and
anti-screening gravity fluctuations

beta-function | running of the coupling



Eichhorn, Held '17, 1707.01107

free fixed point: accommodates $M_t < M_{t,crit}$

16

UV-complete SM: constraining quantum gravity

$$y_t^* = \frac{\sqrt{32}\pi}{3}\sqrt{-G_N\, f_y(\Lambda)}$$

with: $$f_y(\Lambda) = \frac{96 + \Lambda(-235 + \Lambda(103 + 56\Lambda))}{12\pi(3 + 2\Lambda(-5 + 4\Lambda))^2}$$

Eichhorn, Held '17, 1705.02342

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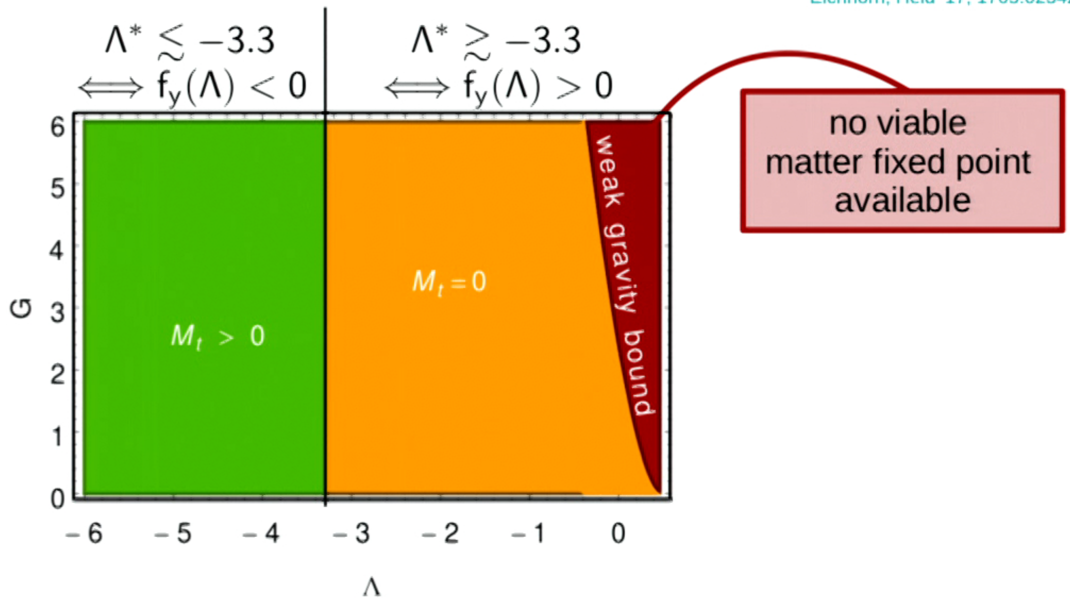

17

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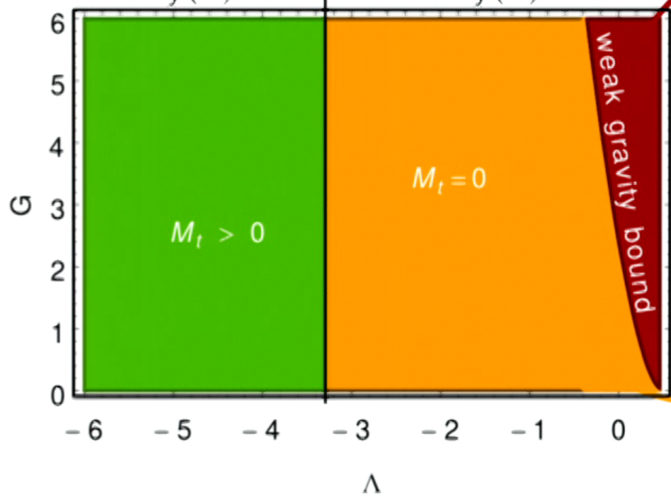
Eichhorn, Held '17, 1705.02342

$\Lambda^* \lesssim -3.3 \iff f_y(\Lambda) < 0$

$\Lambda^* \gtrsim -3.3 \iff f_y(\Lambda) > 0$



no viable matter fixed point available

requires additional bSM physics (e.g. GUTs) to be experimentally viable

17

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Eichhorn, Held '17, 1705.02342

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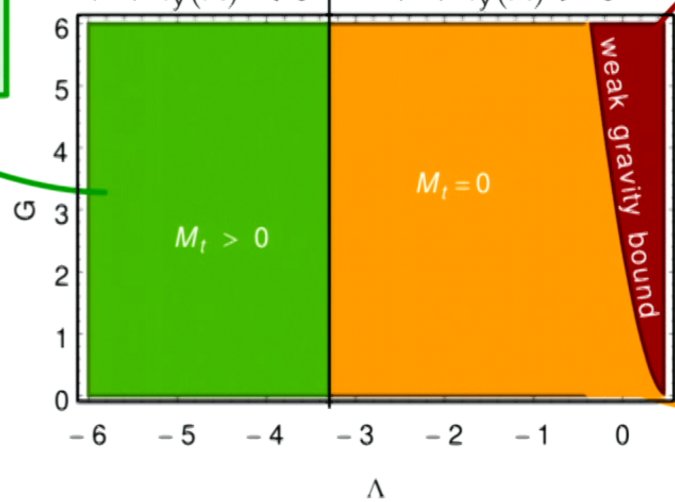
viable IR-dynamics without new physics



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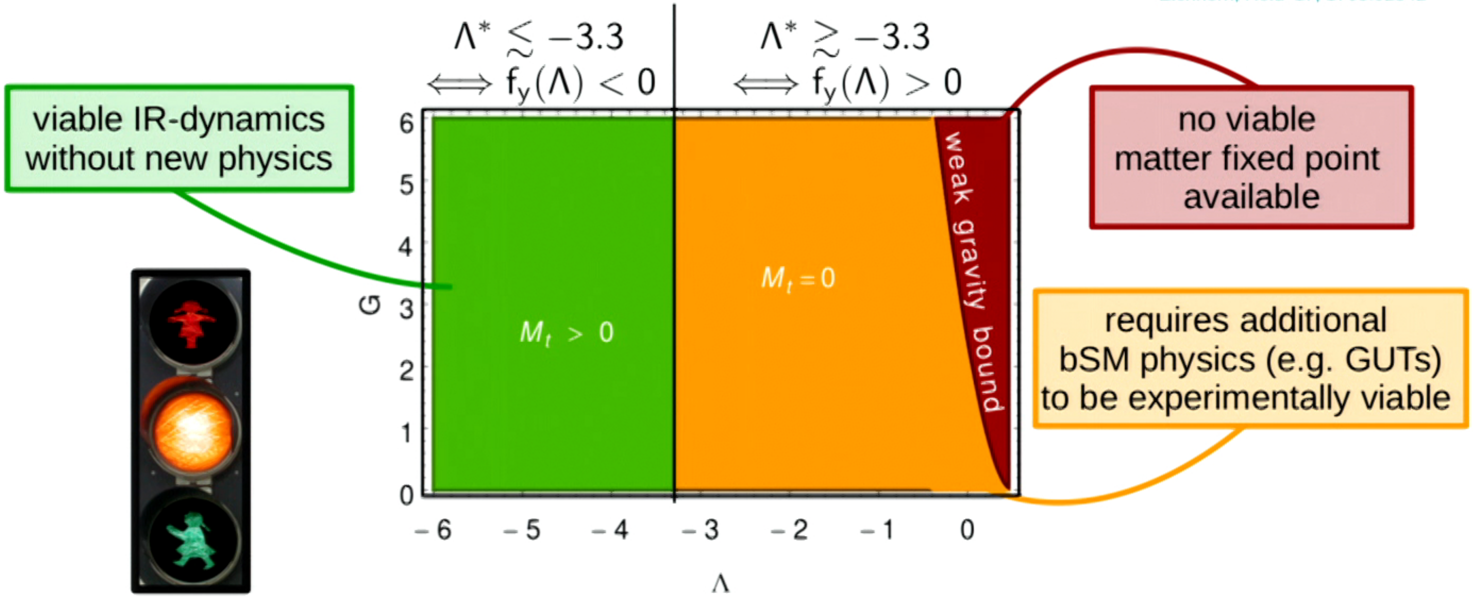
Eichhorn, Held '17, 1705.02342



observation of **matter at accessible energy scales** imposes constraints on the **gravitational dynamics at transplanckian scales**

Top mass from asymptotic safety

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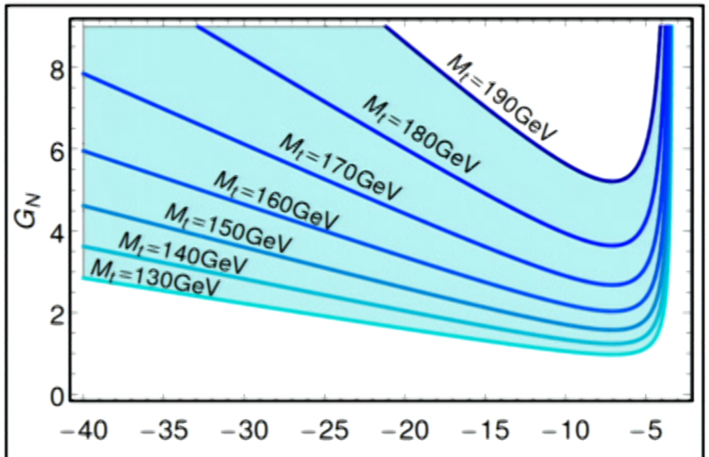
Eichhorn, Held '17, 1705.02342



Eichhorn, Held '17, 1707.01107

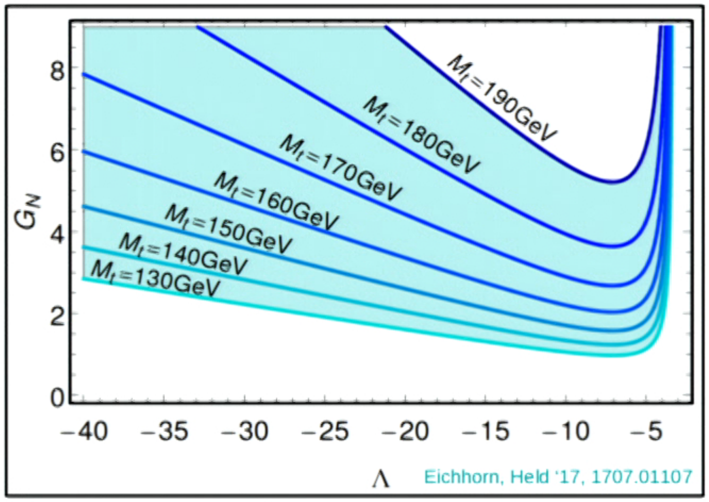
Top mass from asymptotic safety

$$G_N^* = \frac{12\pi}{46 - N_W - N_S + 4N_V}$$

$$\Lambda^* = \frac{3}{4}\left(\frac{2 - 2N_W + N_S + 2N_V}{31 - N_W - N_S + 4N_V}\right)$$

simplified form:
Donà, Eichhorn, Percacci '13, 1311.2898

fermionic matter content of the SM could shift gravity into the **viable regime**



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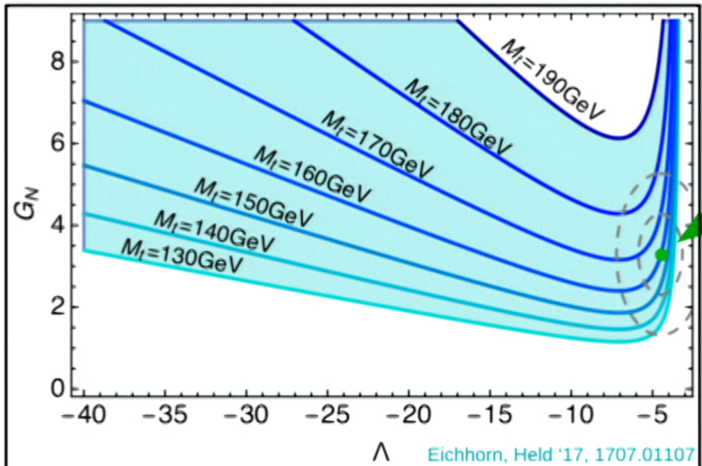
Donà, Eichhorn, Percacci '13, 1311.2898

$N_W = 45$: Weyl fermions
$N_S = 4$: scalars
$N_V = 12$: gauge fields

$\Longrightarrow G_N^* = 3.3\,, \quad \Lambda^* = -4.5$

fermionic matter content of the SM could shift gravity into the **viable regime**



Eichhorn, Held '17, 1707.01107

predicts a top pole mass of $M_{t,\,pole} \approx 170$ GeV **within truncations**

18

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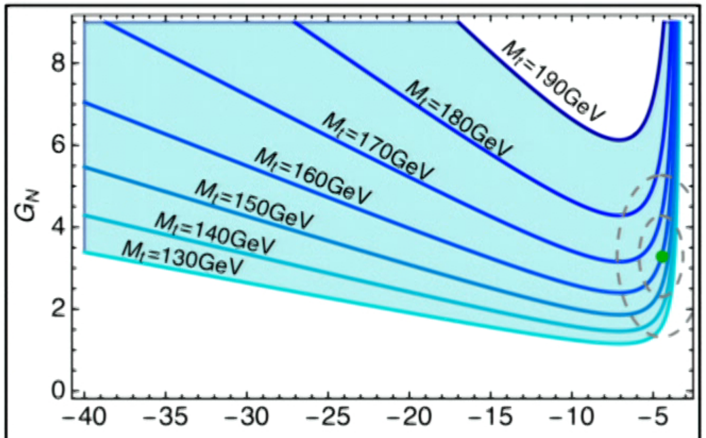

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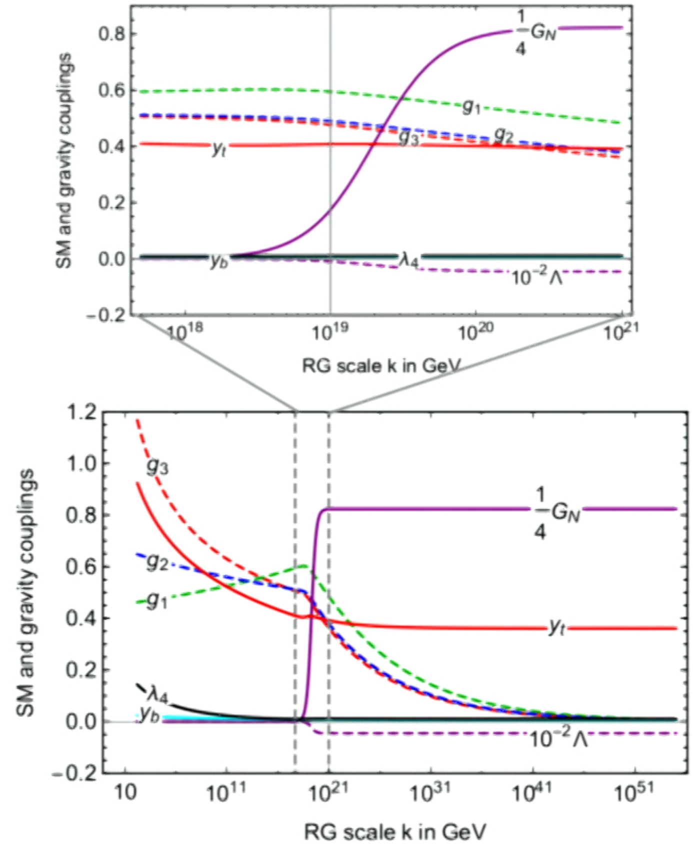

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18

Outlook:
Asymptotic safety of gauge-Yukawa theories

U(1)-hypercharge breaks exchange symmetry $y_t \leftrightarrow y_b$

U(1) explicitly breaks exchange symmetry

$$\beta_{y_t}^{\rm SM} = \frac{y_t}{16\pi^2}\left(\frac{3y_b^2}{2} + \frac{9y_t^2}{2} - 3g_Y^2\left(Y_Q^2 + Y_b^2\right)\right) - y_t\, G_N\, f_y(\Lambda)$$

$$\beta_{y_b}^{\rm SM} = \frac{y_b}{16\pi^2}\left(\frac{9y_b^2}{2} + \frac{3y_t^2}{2} - 3g_Y^2\left(Y_Q^2 + Y_t^2\right)\right) - y_b\, G_N\, f_y(\Lambda)$$

matter fluctuations | gauge fluctuations | quantum gravity fluctuations

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matter fluctuations — gauge fluctuations — quantum gravity fluctuations

- an asymptotically safe U(1) can establish a mass hierarchy in terms of electric charges Q_b and Q_t

$$0 \simeq y_b^{2*} = y_t^{2*} - \left[Q_t^2 - Q_b^2\right] g_Y^{2*}$$

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matter fluctuations | gauge fluctuations | quantum gravity fluctuations

- an asymptotically safe U(1) can establish a mass hierarchy in terms of electric charges Q_b and Q_t
- In SM: Q_t=2/3 , Q_b=-1/3

$$0 \simeq y_b^{2*} = y_t^{2*} - \left[Q_t^2 - Q_b^2\right] g_Y^{2*}$$

$$\Longrightarrow \frac{y_t^{2*}}{g_Y^{2*}} \simeq \frac{1}{3}$$ guarantees a large hierarchy

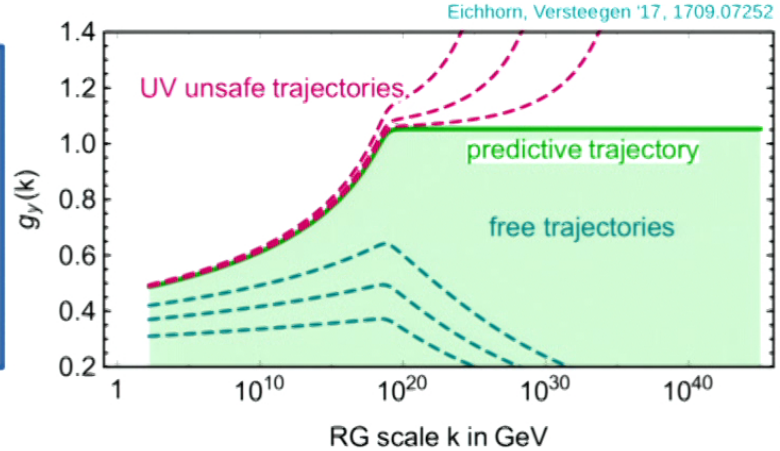
recall:

Daum, Harst, Reuter '10, JHEP 084
Harst, Reuter '11, JHEP 119
Folkerts, Litim, Pawlowsk '12, Phys.Lett.B 709
Christiansen, Eichhorn '17,Phys.Lett.B 770
Christiansen, Litim, Pawlowski, Reichert '17, 1710.04669
Eichhorn, Versteegen '17, 1709.07252

$$\beta_{g_Y} = \frac{g_Y^3}{16\pi^2}\frac{41}{10} - g_Y\, f_g(G, \Lambda, \dots)$$

gauge fluctuations | quantum gravity fluctuations

Eichhorn, Versteegen '17, 1709.07252



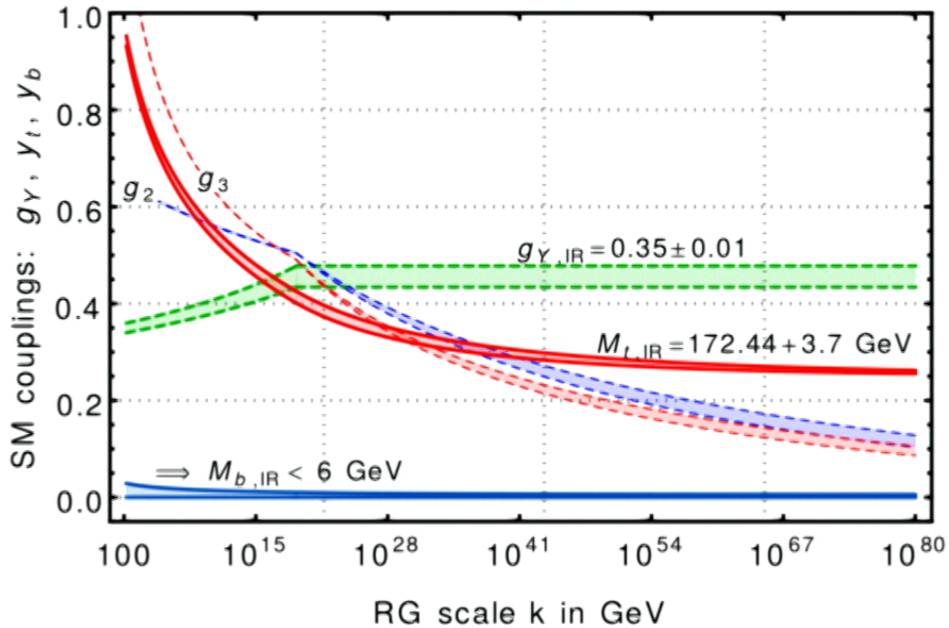
Outlook: hypercharges and mass-hierarchy

$$\beta_{y_t} = \frac{y_t}{32\pi^2}\left(9y_t^2 + 3y_b^2 - \frac{17}{10}g_Y^2\right) + G_N\, y_t\, f_y(\Lambda) + (\text{SM-terms})$$

$$\beta_{y_b} = \frac{y_b}{32\pi^2}\left(9y_b^2 + 3y_t^2 - \frac{1}{2}g_Y^2\right) + G_N\, y_t\, f_y(\Lambda) + (\text{SM-terms})$$

$$\beta_{g_Y} = \frac{g_Y^3}{16\pi^2}\,\frac{41}{10} - G_N\, g_Y\, f_g(\Lambda)$$

$f_g\,(g_{Y,\,\mathrm{IR}})$, $f_y\,(M_{t,\,\mathrm{IR}})$ fixed



Eichhorn, Held, in prep.

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recall

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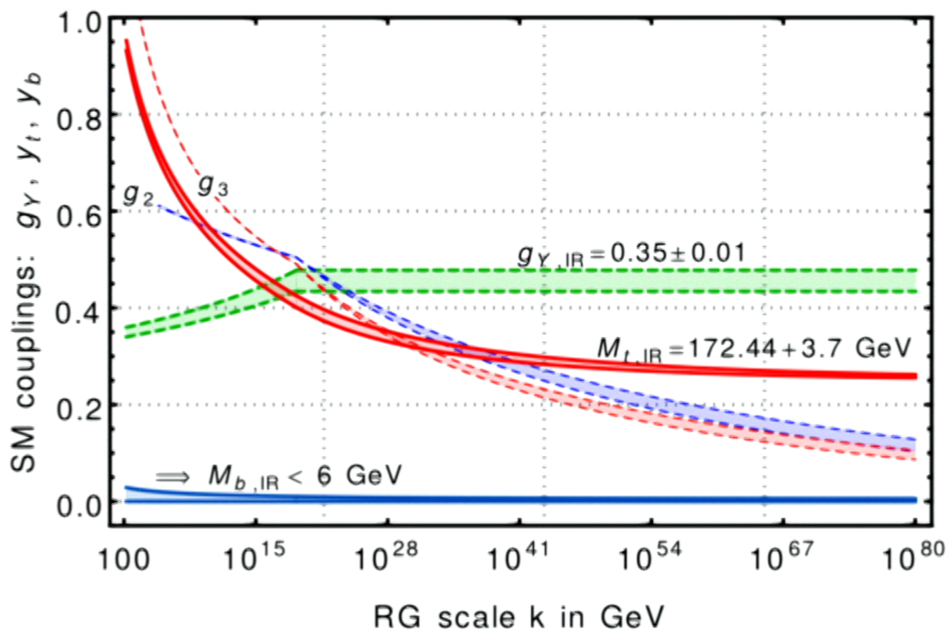


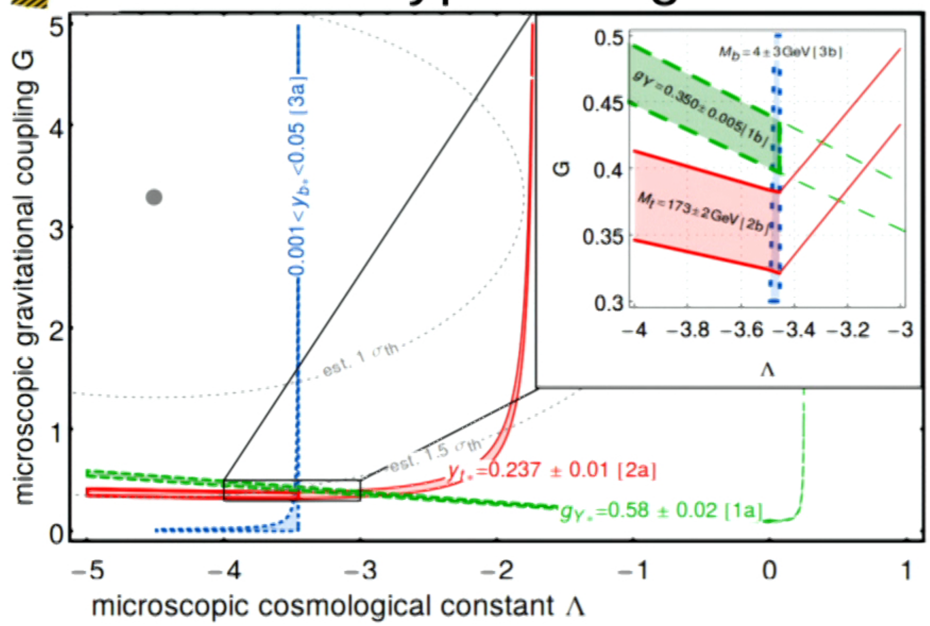
$g_Y^{2*} \simeq 3y_t^{2*}$

in the gravitating Standard Model

A gravitating Standard Model could also predict a significant top-bottom mass-difference

Eichhorn, Held, in prep.

Outlook: hypercharges and mass-hierarchy



Theory:

[1a] Eichhorn, Held, 1707.01107 (2017)

[2a] Eichhorn, Versteegen, 1709.07252 (2017)

[3a] Eichhorn, Held, in prep. (2017)

Experiment:

[1b] $g_{Y,exp}$=0.3497 Buttazzo et. Al. (2013)

[2b] $M_{t,exp}$=172.35 ± 0.64 CMS, Phys.Rev. D93 (2016)

[3b] $M_{b,exp}$=4.18 ± 0.03 PDG, Phys.Rev. D86 (2012)

Eichhorn, Held, in prep.

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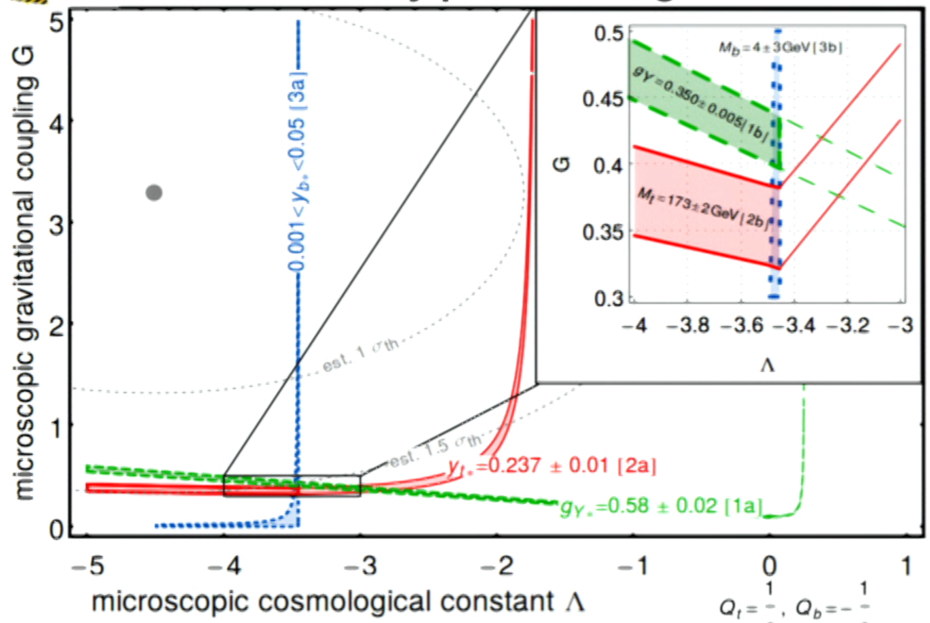

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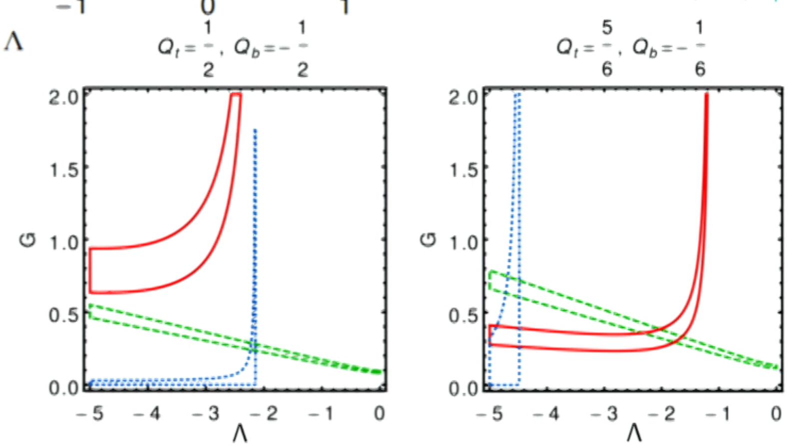

$$\Rightarrow \boxed{\left(g_Y^*,\, y_t^*,\, y_b^*\right)(G_N, \Lambda)}$$

only works for electric charges of the SM

$$Q_t = \frac{2}{3},\ Q_b = -\frac{1}{3}$$

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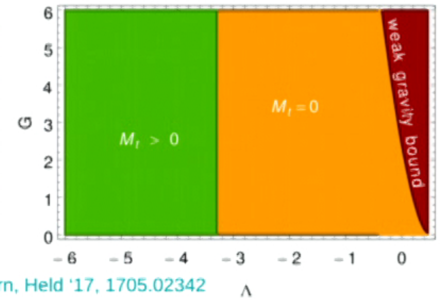
Conclusions

- viability of matter-gravity systems constrains quantum gravity: **weak-gravity bound**



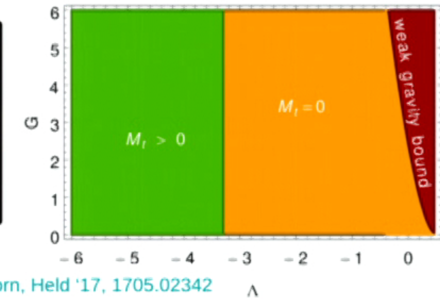
Eichhorn, Held '17, 1705.02342

Conclusions

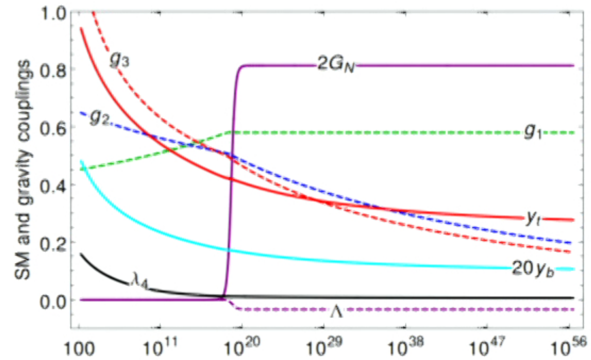
- viability of matter-gravity systems constrains quantum gravity:
  weak-gravity bound

- asymptotically safe quantum gravity could **UV-complete the Standard Model** (or GUTs)

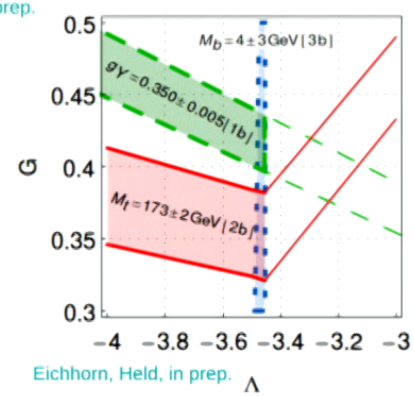
- **higher predictive power** than the Standard Model
  (**fewer** ~~19~~ free parameters)
  g_1, M_t , M_b



Eichhorn, Held '17, 1705.02342



Eichhorn, Held '17, 1707.01107
Eichhorn, Held, in prep.



Eichhorn, Held, in prep.

22

Conclusions

- viability of matter-gravity systems constrains quantum gravity: **weak-gravity bound**

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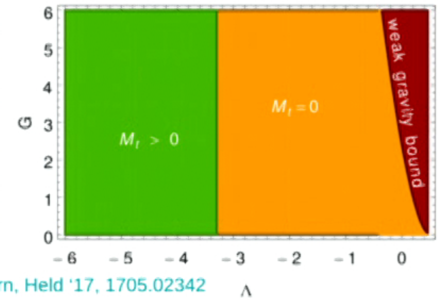
- **higher predictive power** than the Standard Model (**fewer** ~~19~~ free parameters) **g_1, M_t, M_b**

- **convergence** of FP values for microscopic gravity couplings **needs to be studied in the future**

– Thank you for your attention. –



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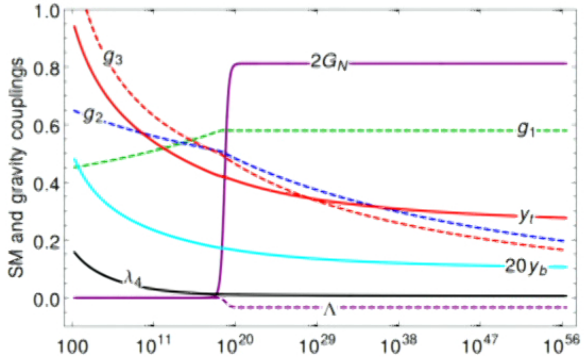

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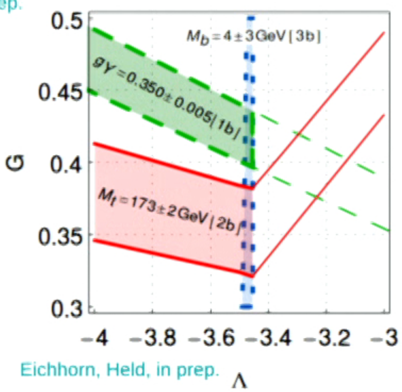

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