Title: Towards the top quark mass from asymptotic safety

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Abstract: <p>I will discuss a proposed mechanism to fix the value of the top quark mass from asymptotic safety of gravity and matter, and will review the status of the proposal.</p>

Quantum gravity and matter in asymptotic safety

idea: asymptotic safety paradigm could:

- Quantum gravity + Standard Model (+ extensions?) at transplanckian scales

  ⟶ universality (extend range of QFT beyond Mpl; not necessarily ``fundamental")

- enhanced predictive power

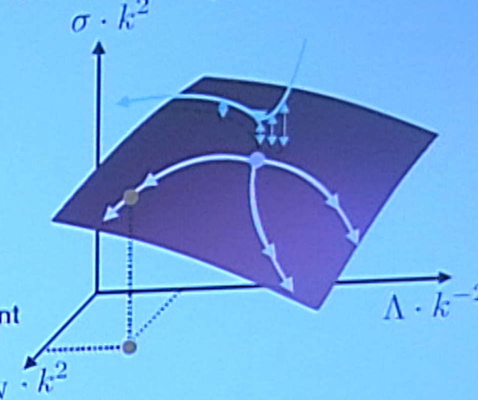
  ⟶ explanatory power

  ⟶ testability

status:

- first indications exist, but open challenges!

Quantum gravity in asymptotic safety



Renormalization Group fixed point in space of all couplings compatible with symmetry

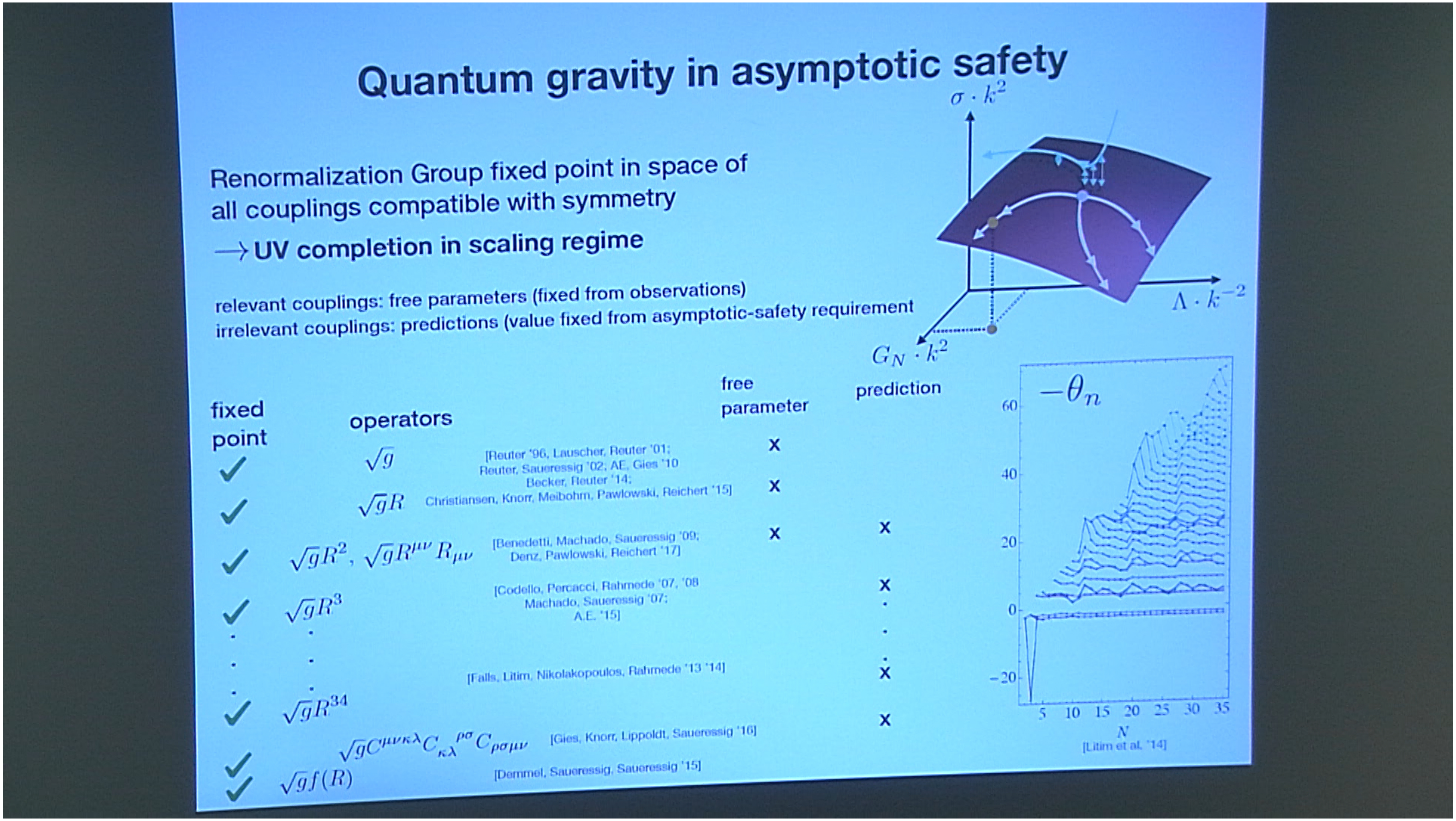
$\rightarrow$ **UV completion in scaling regime**

relevant couplings: free parameters (fixed from observations)
irrelevant couplings: predictions (value fixed from asymptotic-safety requirement

fixed point	operators		free parameter	prediction
✓	$\sqrt{g}$	[Reuter '96, Lauscher, Reuter '01; Reuter, Saueressig '02; AE, Gies '10	x	
✓	$\sqrt{g}R$	Becker, Reuter '14; Christiansen, Knorr, Meibohm, Pawlowski, Reichert '15]	x	
✓	$\sqrt{g}R^2$, $\sqrt{g}R^{\mu\nu}R_{\mu\nu}$	[Benedetti, Machado, Saueressig '09; Denz, Pawlowski, Reichert '17]	x	x
✓	$\sqrt{g}R^3$	[Codello, Percacci, Rahmede '07, '08 Machado, Saueressig '07; A.E. '15]		x
.	.			.
.	.			.
.	.	[Falls, Litim, Nikolakopoulos, Rahmede '13 '14]		x
✓	$\sqrt{g}R^{34}$			x
✓	$\sqrt{g}C^{\mu\nu\kappa\lambda}C_{\kappa\lambda}{}^{\rho\sigma}C_{\rho\sigma\mu\nu}$	[Gies, Knorr, Lippoldt, Saueressig '16]		
✓	$\sqrt{g}f(R)$	[Demmel, Saueressig, Saueressig '15]		

tool: functional RG equation in truncations of theory space
(well-tested for interacting fixed points)
[Wetterich '93, Reuter '96]

(Ising model [Canet et al. '03, Litim, Zappala '10]**,**
Gross-Neveu (Yukawa) [Knorr '16, Gies et al. '17, Classen, Herbut, Scherer '17]**,**
multicritical points [AE, Mesterhazy, Scherer '14]**...)**



Quantum gravity in asymptotic safety
$\sigma \cdot k^2$
$\Lambda \cdot k^{-2}$
$G_N \cdot k^2$
Renormalization Group fixed point in space of all couplings compatible with symmetry
$\longrightarrow$ UV completion in scaling regime
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fixed point
operators
free parameter
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$\sqrt{g}$
[Reuter '96, Lauscher, Reuter '01; Reuter, Saueressig '02; AE, Gies '10 Becker, Reuter '14; Christiansen, Knorr, Meibohm, Pawlowski, Reichert '15]
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$\sqrt{g}f(R)$
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$-\theta_n$
60
40
20
0
−20
5
10
15
20
25
30
35
N
[Litim et al. '14]

Challenges for the field

- quantitative convergence $\longrightarrow$ successive enlargement of truncations
  [in progress]
  $\longrightarrow$ lattice studies?
  [Ambjorn, Jurkiewicz, Loll; Laiho]
- Lorentzian signature $\longrightarrow$ first step: study in ADM decomposition
  [Saueressig et al.] for interacting matter- gravity systems: [A.E., M. Schiffer, in progress]
- background independence $\longrightarrow$ first step: distinguish background-prop. from fluctuation prop.
  e.g., [Meibohm, Pawlowski, Reichert '14, Dona, A.E., Labus, Percacci '15, A.E., Labus, Pawlowski, Reichert '18] & work in progress
  $\longrightarrow$ shift Ward identity
  [Morris '16; Percacci, Vacca '17; Ohta '17; A.E., Labus, Pawlowski, Reichert '18]
  $\longrightarrow$ connection to tensor models?
  [A.E., Koslowski '13,'14,'17; AE, Koslowski, Lumma, Pereira, in progress]
- unitarity? interpretation: no poles of flat-space propagator with wrong sign
  $R^2 + R_{\mu\nu}^2$ proposal: mass of "ghost" runs "away" towards higher scales
  [Benedetti, Machado, Saueressig '09]
  [Saueressig et al. '18]
  $\longrightarrow$ infinite-dimensional truncations, include matter!
  $\longleftrightarrow$ "fundamental"?
- phenomenologically viable? $\longrightarrow$ connection to particle physics

Towards the top quark mass from asymptotic safety

Quantum gravity “effects” at the electroweak scale?

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AS Quantum gravity effects on matter (in truncations of dynamics):

- higher-order couplings induced (present at UV fixed point)

[AE, Gies '11; AE '12; Meibohm, Pawlowski '14; AE, Held, Pawlowski '16; AE, Lippoldt, Skrinjar '17]

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- fixed points in marginal couplings generated

  $\longrightarrow$ logarithmic running below M_{pl} preserves "memory" of UV physics

  [Daum, Reuter '09; Eichhorn, Held '17 '18, Eichhorn, Versteegen '17]

Mechanism for "retrodiction" of SM couplings

for marginally irrelevant SM couplings:

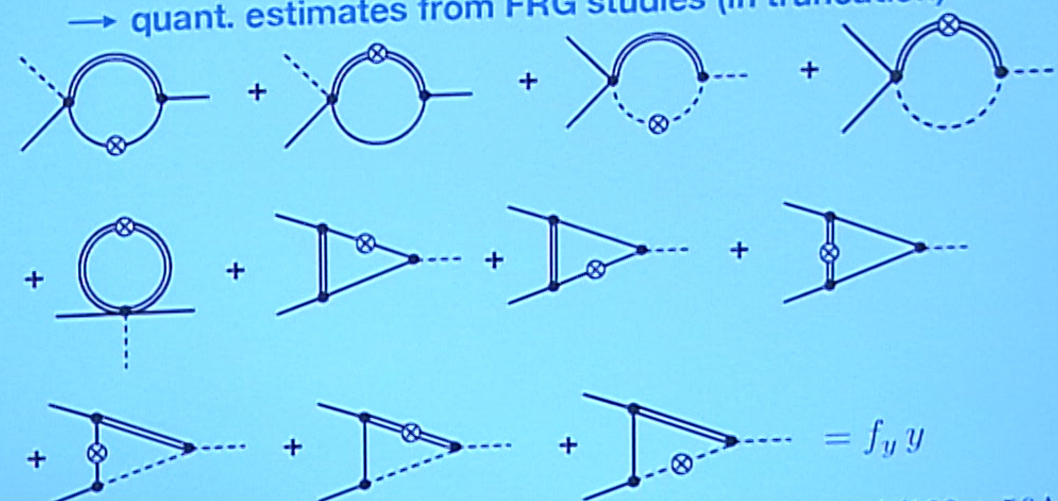
$$\beta_{y_t} = f_y\, y_t + \frac{1}{32\pi^2}\left(9y_t^3 + 3y_b^2 y_t + y_t\left(-16g_3^2 - \frac{9}{2}g_2^2 - \frac{17}{10}g_1^2\right)\right)$$

QG contribution (FRG) ~ dimensional term

f_y: effective strength of QG fluc's

⟶ quant. estimates from FRG studies (in truncation)

$\beta_{y\,\mathrm{grav}} =$



$= f_y\, y$

e.g. Einstein-Hilbert truncation $f_y = G\,\dfrac{96 + \Lambda(-235 + \Lambda(103 + 56\Lambda))}{12\pi(3 + 2\Lambda(-5 + 4\Lambda))^2}$

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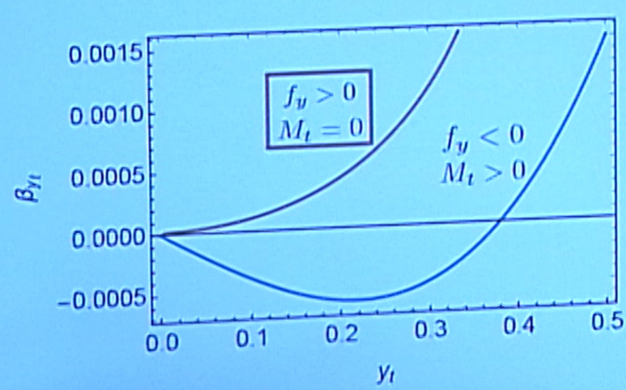
$\rightarrow y_{t\,*} = \frac{\sqrt{-f_y\, 32\pi^2}}{3}$ IR attractive!



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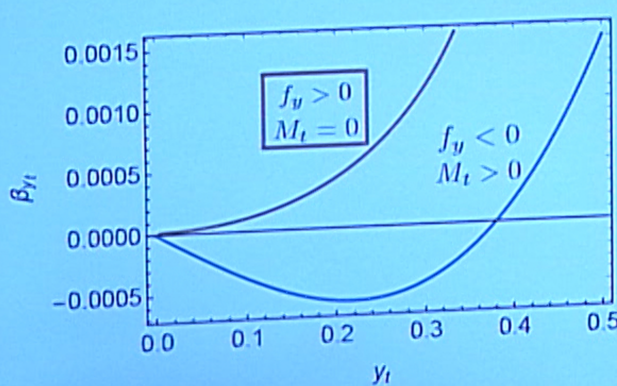
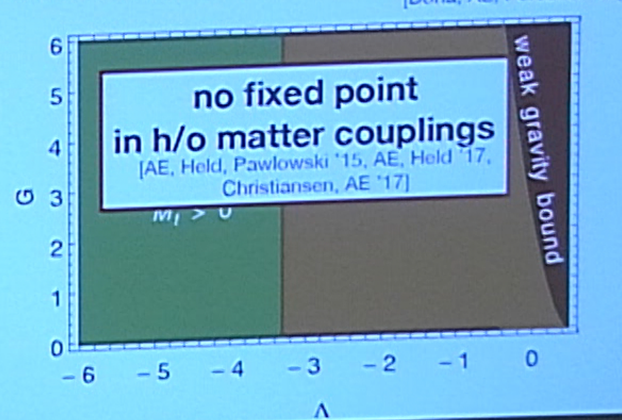
What is f_y? $f_y = G\,\frac{96 + \Lambda(-235 + \Lambda(103 + 56\Lambda))}{12\pi(3 + 2\Lambda(-5 + 4\Lambda))^2}$

Einstein-Hilbert-truncation:

backreaction of matter crucial

[Dona, AE, Percacci '13]





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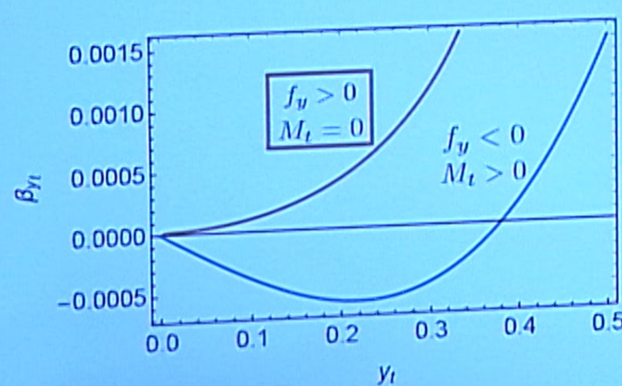

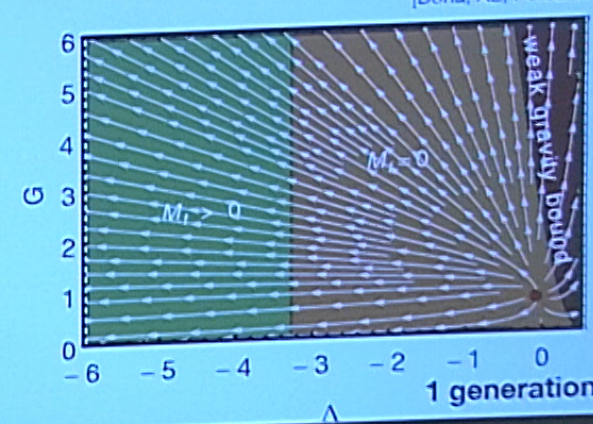

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$$\beta_{y_t} = f_y\, y_t + \frac{1}{32\pi^2}\left(9y_t^3 + 3y_b^2 y_t + y_t\left(-16g_3^2 - \frac{9}{2}g_2^2 - \frac{17}{10}g_1^2\right)\right)$$

$$\beta_{g_i} = f_g\, g_i + \#_i g_i^3 \qquad f_g \leq 0$$

[Daum, Harst, Reuter '10; Folkerts, Litim, Pawlowski '11; Harst, Reuter '11, Christiansen, AE '17, AE, Versteegen '17]

$$\rightarrow y_{t\,*} = \frac{\sqrt{-f_y\, 32\pi^2}}{3}$$ **IR attractive!**

What is f_y?

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

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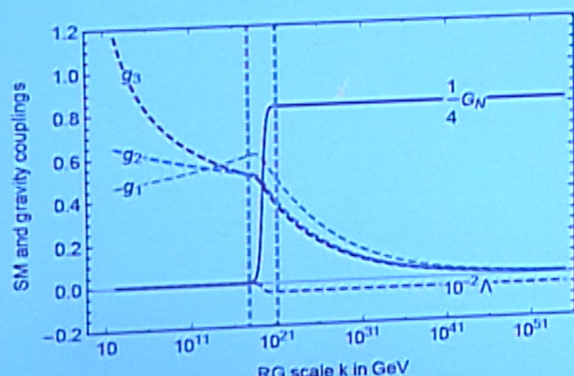

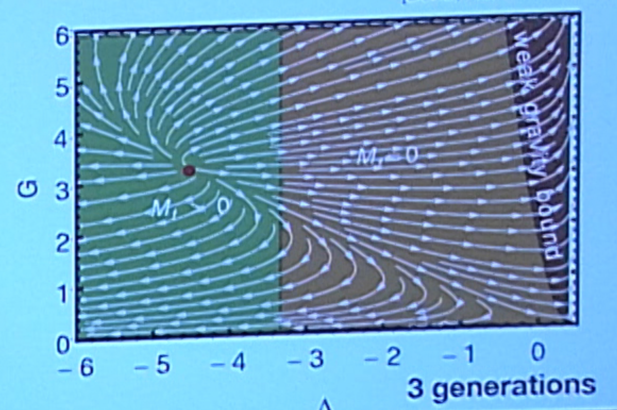

3 generations

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for marginally irrelevant SM couplings:

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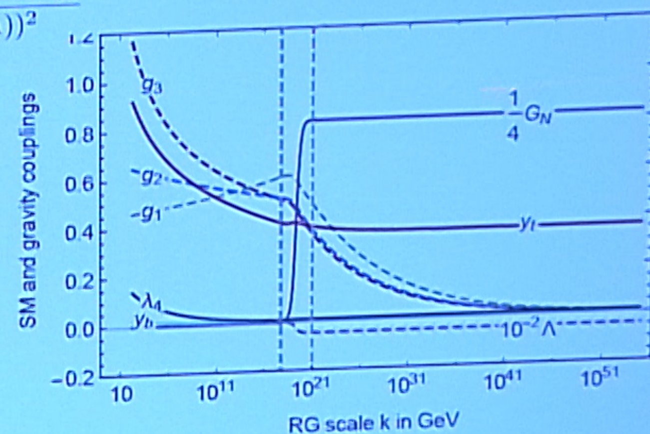
$$- f_y\, y_t \qquad f_y = G\,\frac{96 + \Lambda(-235 + \Lambda(103 + 56\Lambda))}{12\pi(3 + 2\Lambda(-5 + 4\Lambda))^2}$$

$M_t \approx 170\,\mathrm{GeV}$



$$\beta_{g_i} = f_g\, g_i + \#_i g_i^3$$

$$f_g = -G\,\frac{5(1-4\Lambda)}{18\pi(1-2\Lambda)^2}$$

$$\beta_{G_N} = 2\,G_N - G_N^2\, f_{G_N}(\Lambda)$$

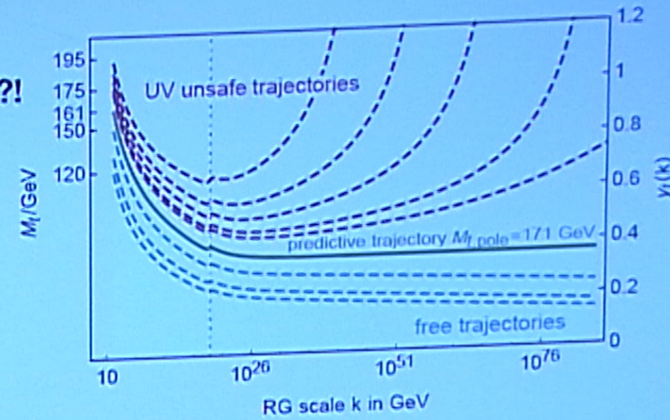
$$\beta_\Lambda = -2\,\Lambda - G_N\,\Lambda\, f_{G_N}(\Lambda)$$

$$-\frac{G_N}{2\pi}\left(7 - \frac{3}{2(3-4\Lambda)} + N_W - \frac{N_S}{2} - N_V - \frac{5}{2(1-2\Lambda)} - 8\ln(3/2)\right)$$

Mechanism for "retrodiction" of SM couplings

→ QG effects on matter @ electroweak scale?!

→ *marginal* couplings restricted by AS



Mechanism for "retrodiction" of SM couplings

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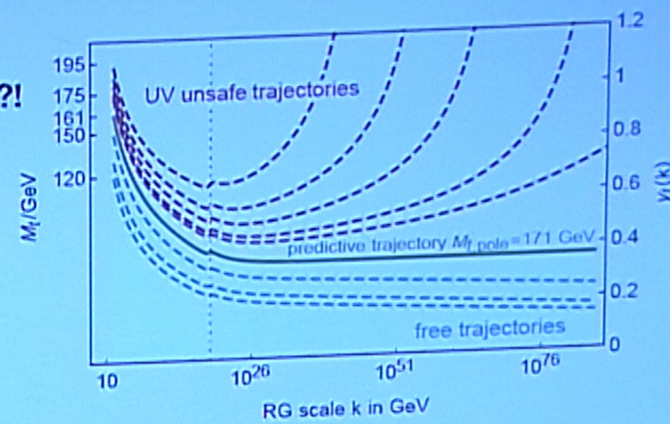
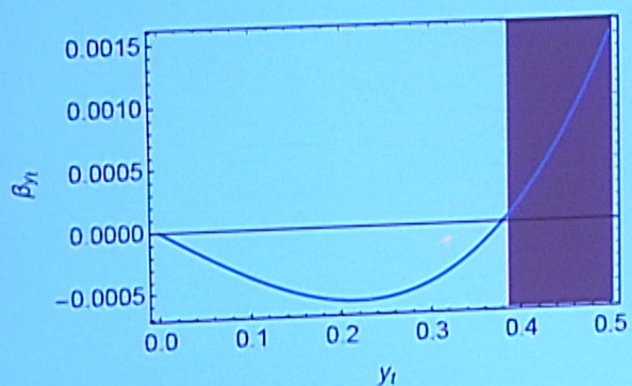
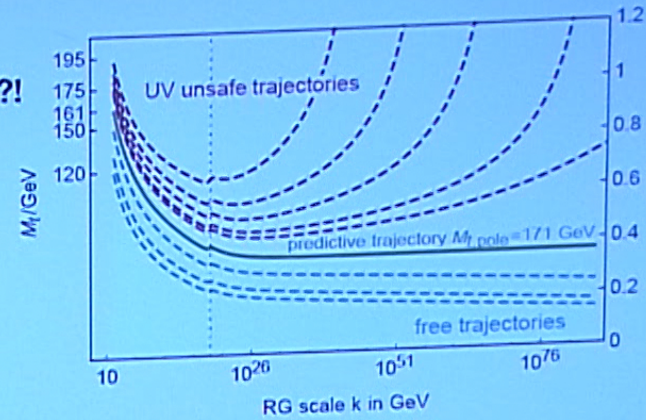
→ predictive trajectory
= upper bound





Mechanism for “retrodiction” of SM couplings



→ QG effects on matter @ electroweak scale?!

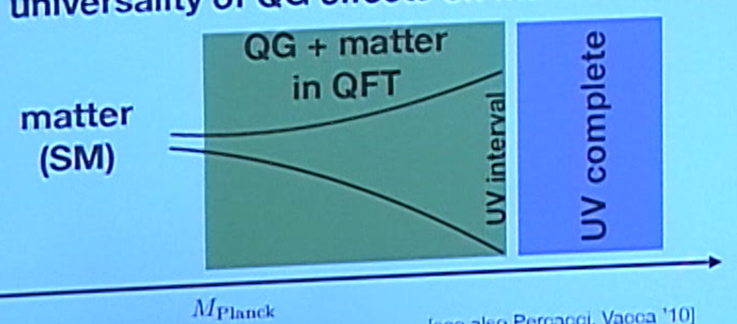
→ *marginal* couplings restricted by AS

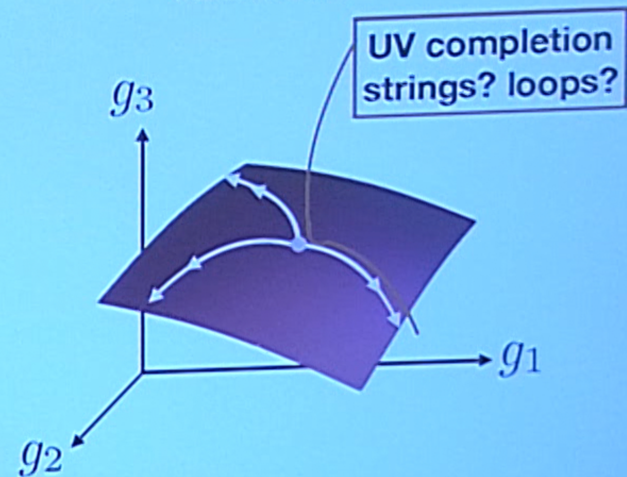
→ predictive trajectory
= upper bound

→ relevance of asymptotic safety
beyond "fundamental" UV model

→ $y_{t\,*} = \frac{\sqrt{-f_y\, 32\pi^2}}{3}$ IR attractive!

→ universality of QG effects on matter





[see also Percacci, Vacca '10]

Mechanism for “retrodiction” of SM couplings

beyond the “simplest” truncation:

(expansion scheme: combined vertex & derivative exp.)

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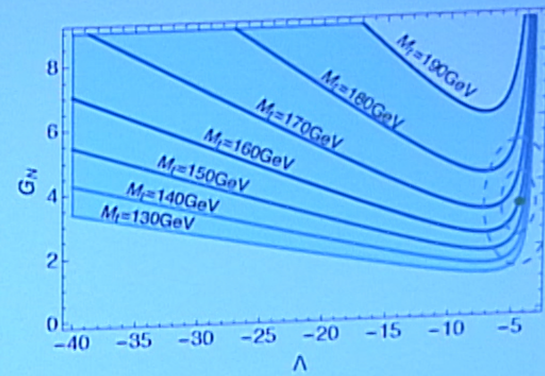
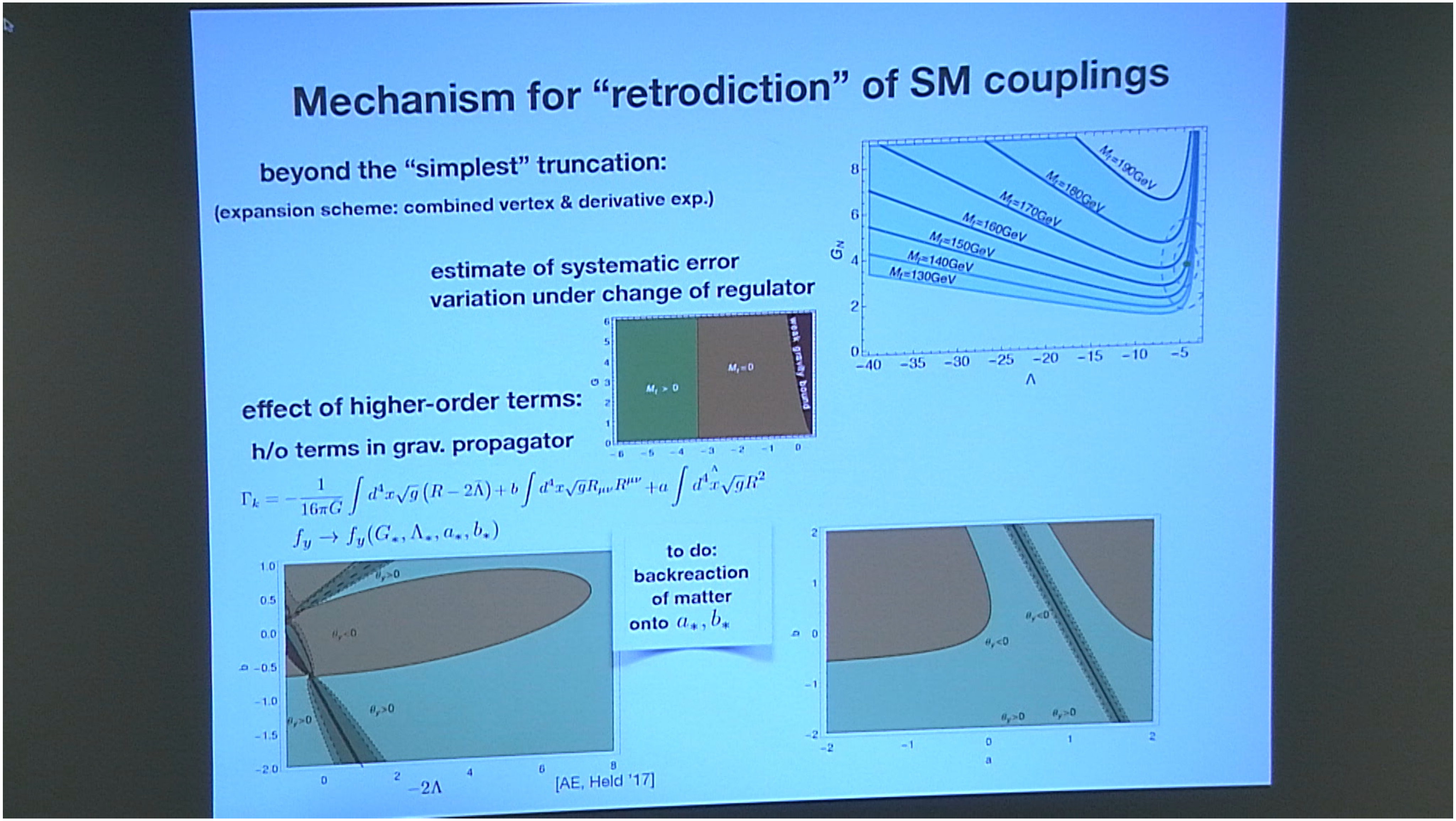


estimate of systematic error
variation under change of regulator

mechanism (qualitative) robust



Mechanism for "retrodiction" of SM couplings
beyond the "simplest" truncation:
(expansion scheme: combined vertex & derivative exp.)
estimate of systematic error
variation under change of regulator
effect of higher-order terms:
h/o terms in grav. propagator
$\Gamma_k = -\frac{1}{16\pi G}\int d^4x\sqrt{g}\,(R-2\bar{\Lambda}) + b\int d^4x\sqrt{g}R_{\mu\nu}R^{\mu\nu} + a\int d^4x\sqrt{g}R^2$
$f_y \to f_y(G_*, \Lambda_*, a_*, b_*)$
to do:
backreaction
of matter
onto a_*, b_*
[AE, Held '17]
M_t=190GeV
M_t=180GeV
M_t=170GeV
M_t=160GeV
M_t=150GeV
M_t=140GeV
M_t=130GeV
G_N
Λ
$M_t > 0$
$M_t = 0$
weak gravity bound
-2Λ
$\theta_y > 0$
$\theta_y < 0$

Mechanism for "retrodiction" of SM couplings

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(expansion scheme: combined vertex & derivative exp.)

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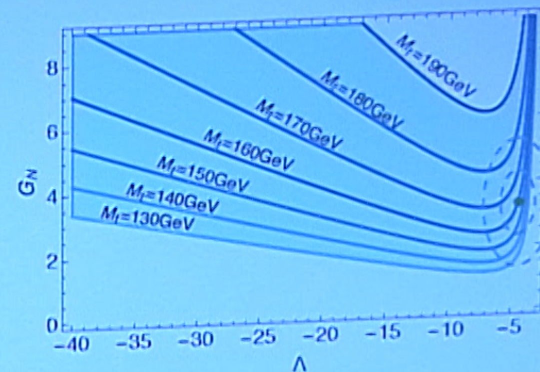

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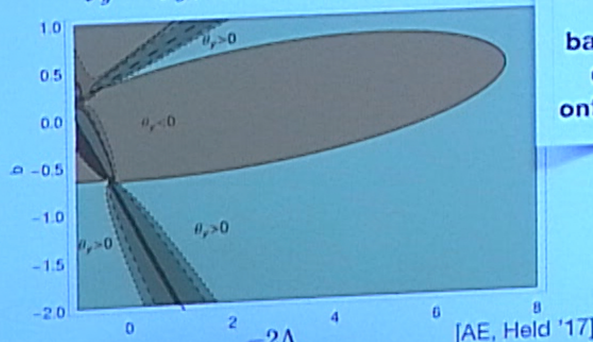
$$f_y \to f_y(G_*, \Lambda_*, a_*, b_*)$$



[AE, Held '17]

to do: backreaction of matter onto a_*, b_*

h/o matter interactions

gravity-induced matter interactions

[AE, Gies '11; AE '12; Meibohm, Pawlowski '14; AE, Held, Pawlowski '16]

e.g. $\lambda_A(\bar{\psi}\gamma_\mu\gamma_5\psi)^2$ **,** $\chi\bar{\psi}\nabla\psi(\partial\phi)^2$

contribution to β_y suppressed compared to f_y

explicit calculation: [AE, Held '17]

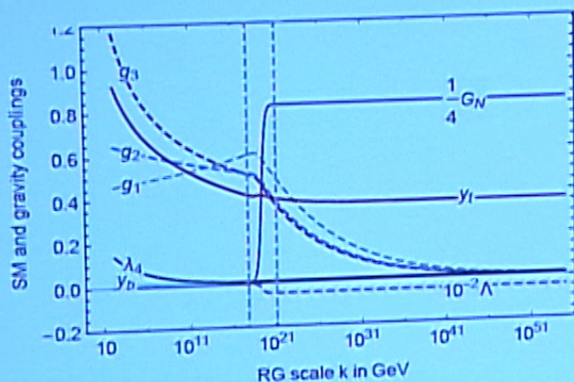
structural argument:

$$\lambda_{A\,*} \sim G_*$$

matter loop: $\beta_{y_t}\Big|_{\lambda_A} \sim \frac{1}{16\pi^2} y_t\,\lambda_*$

Summary

intriguing hint for connection between particle physics & AS quantum gravity



potential mechanism for "retrodictions": antiscreening gravity fluctuations balance screening matter fluctuations

restricts microscopic grav. parameter space in truncations

worthwhile to follow up further!

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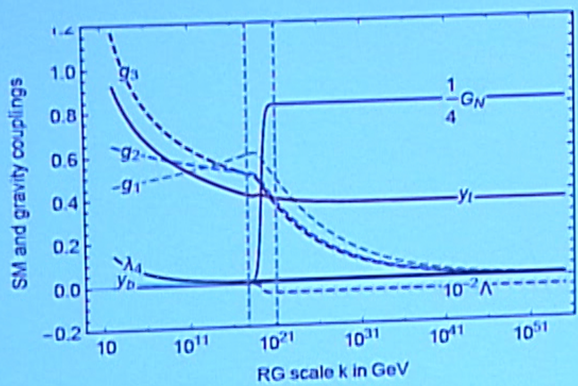
intriguing hint for connection between particle physics & AS quantum gravity



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Future:

- truncations:
  - h/o gravity couplings with backreaction of matter
  - alternative methods: lattice?
- connection to other paradigms for UV completion (universality)
- towards quantitative viability:
  - SM only?
  - BSM?