Quantum-gravity effects on a Higgs-Yukawa model

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with Aaron Held
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Emmy Noether-Programm
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Observational tests of quantum gravity

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Problem: It’s tough to probe the microscopic structure of spacetime directly

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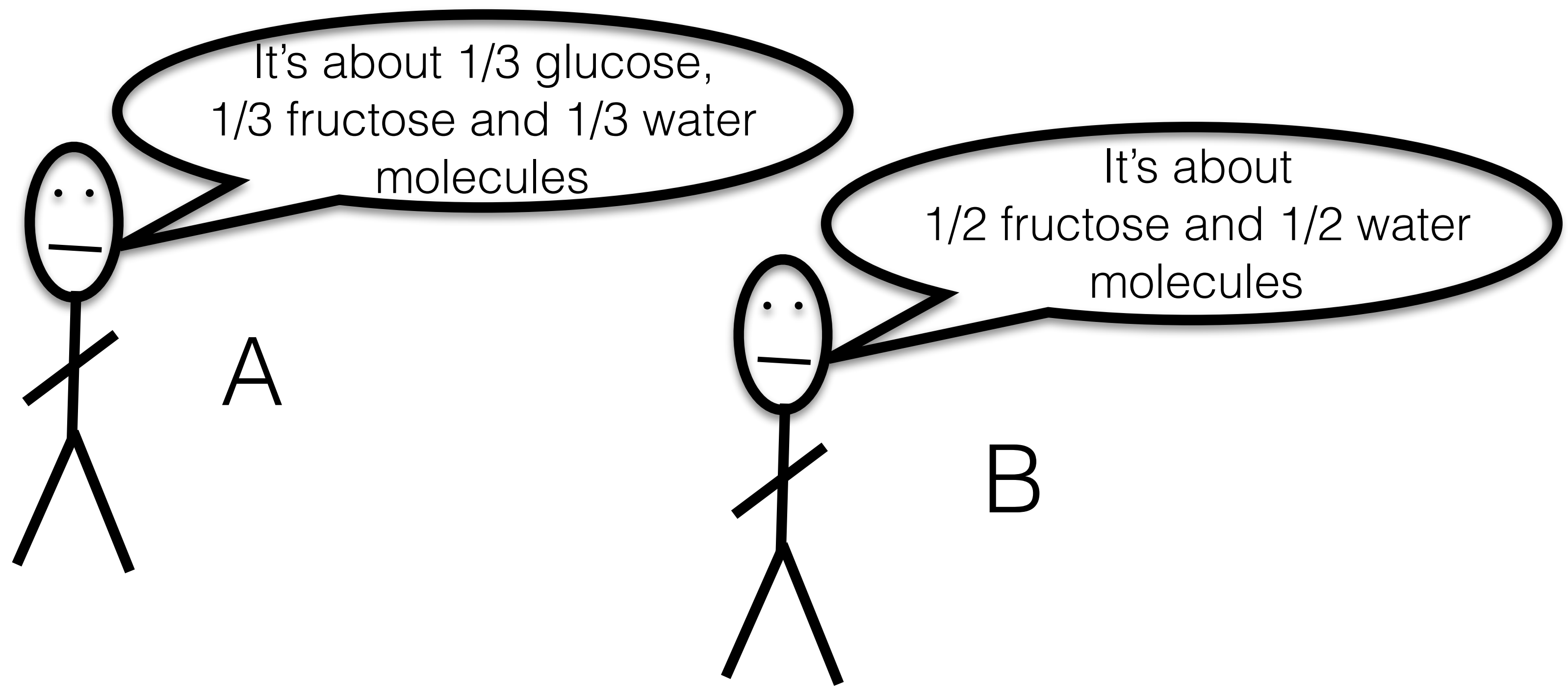

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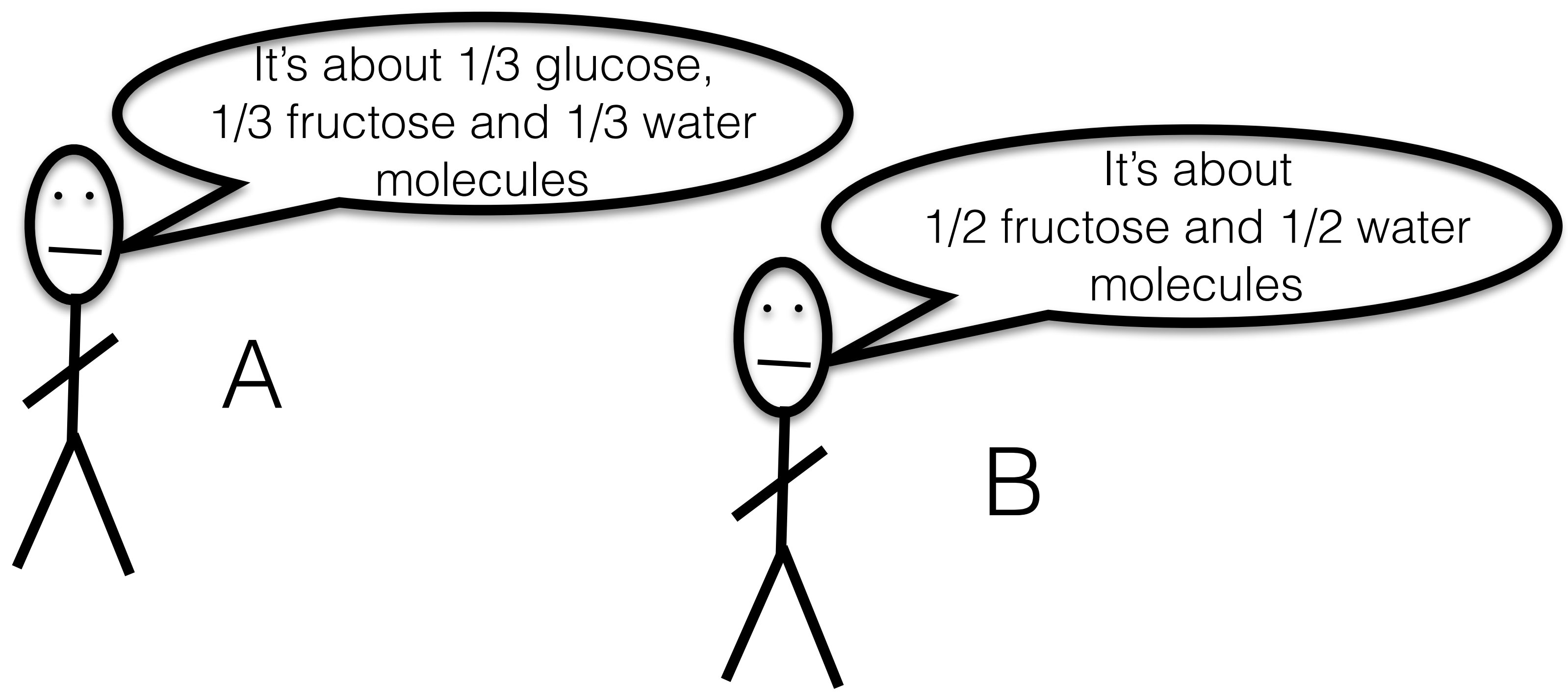

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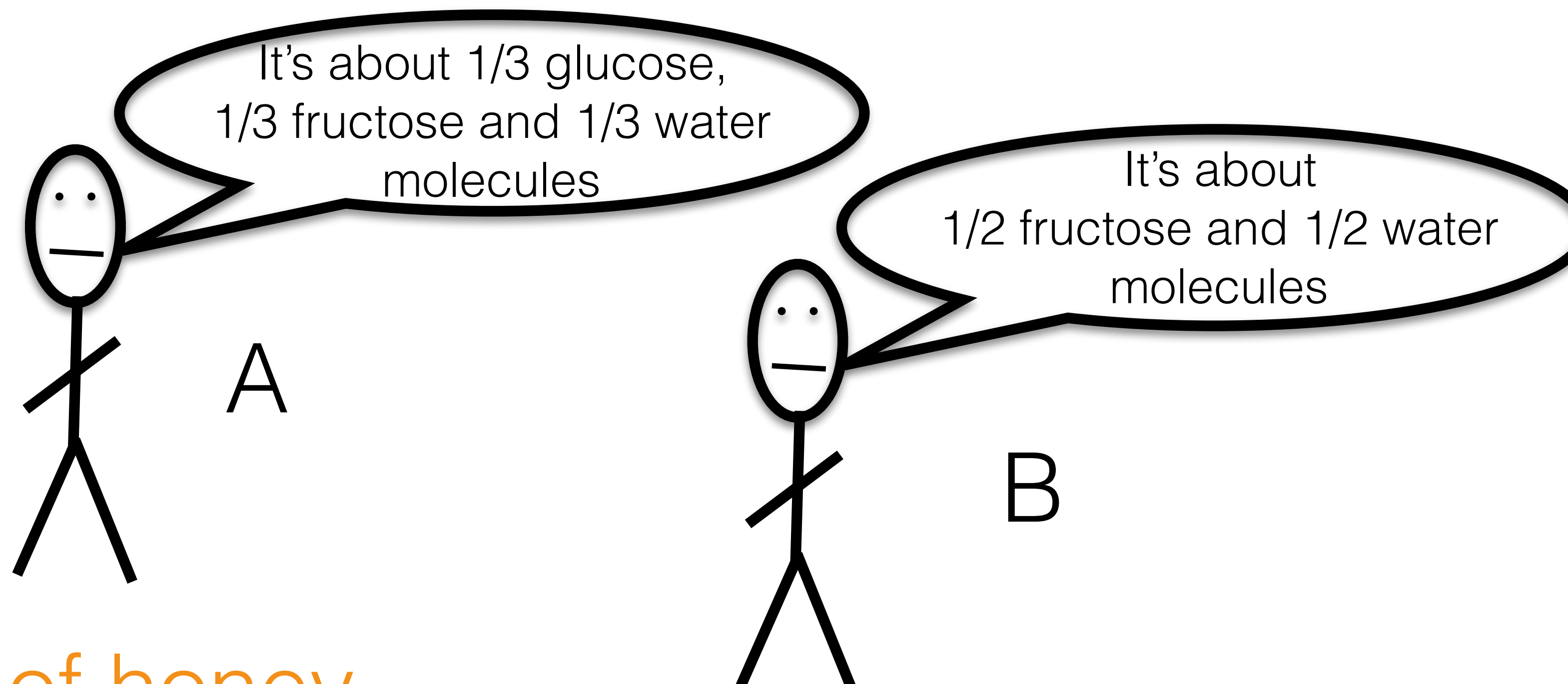

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(measurement at scales >> molecular scale; calculable from microscopic model)

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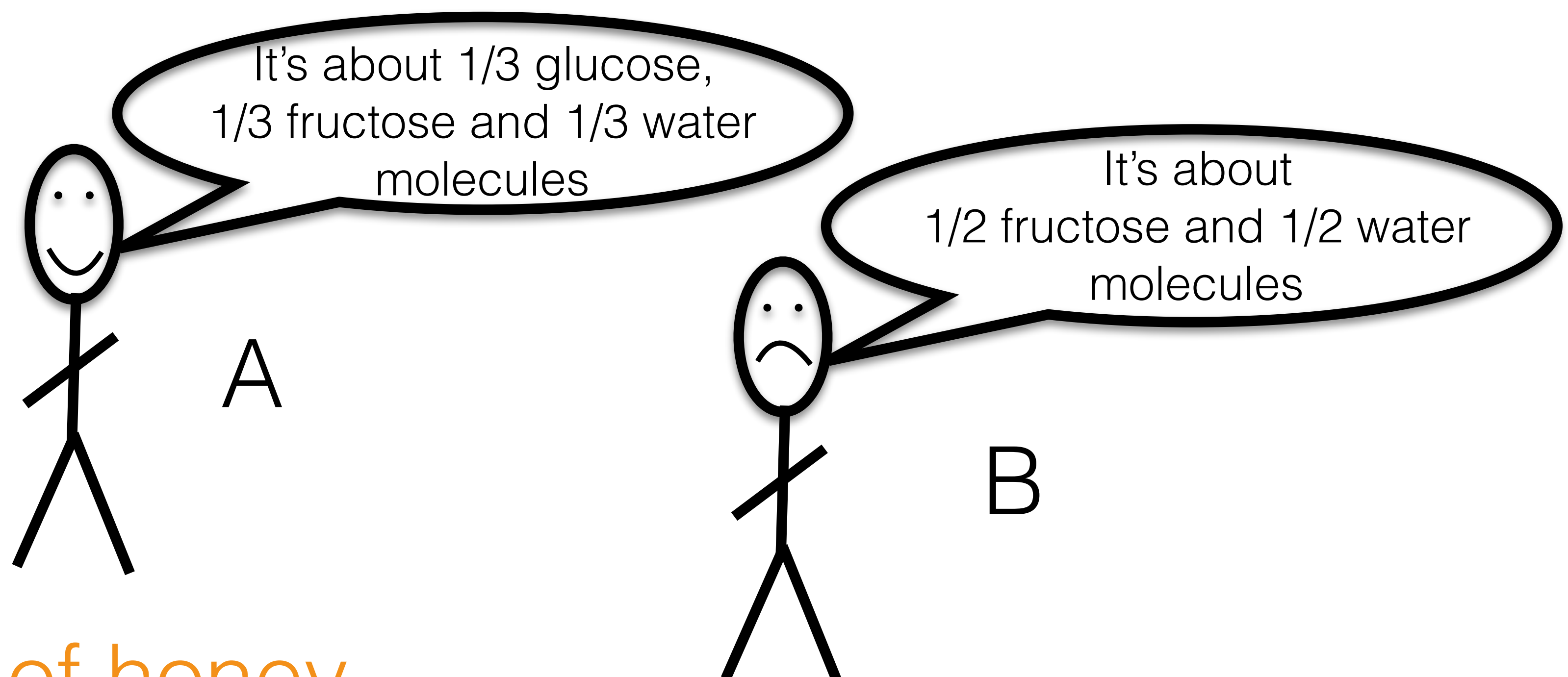

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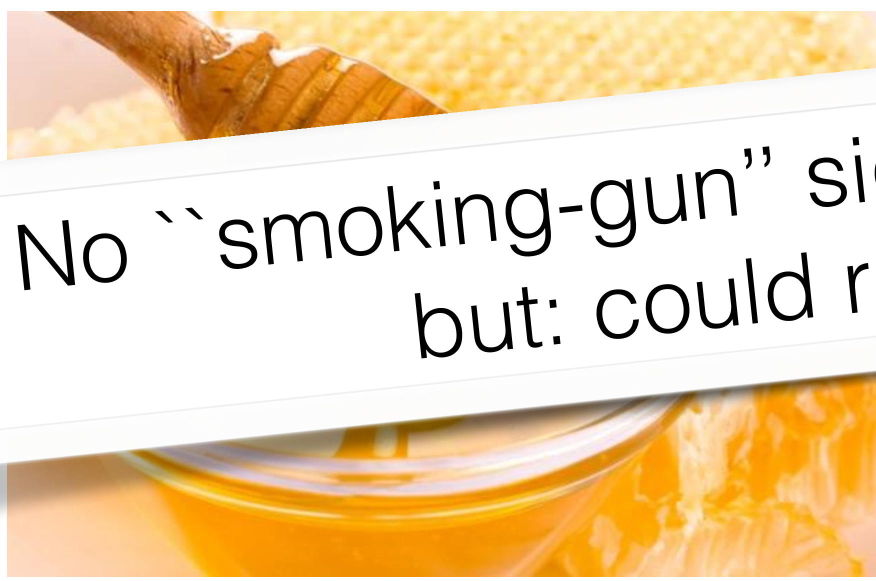

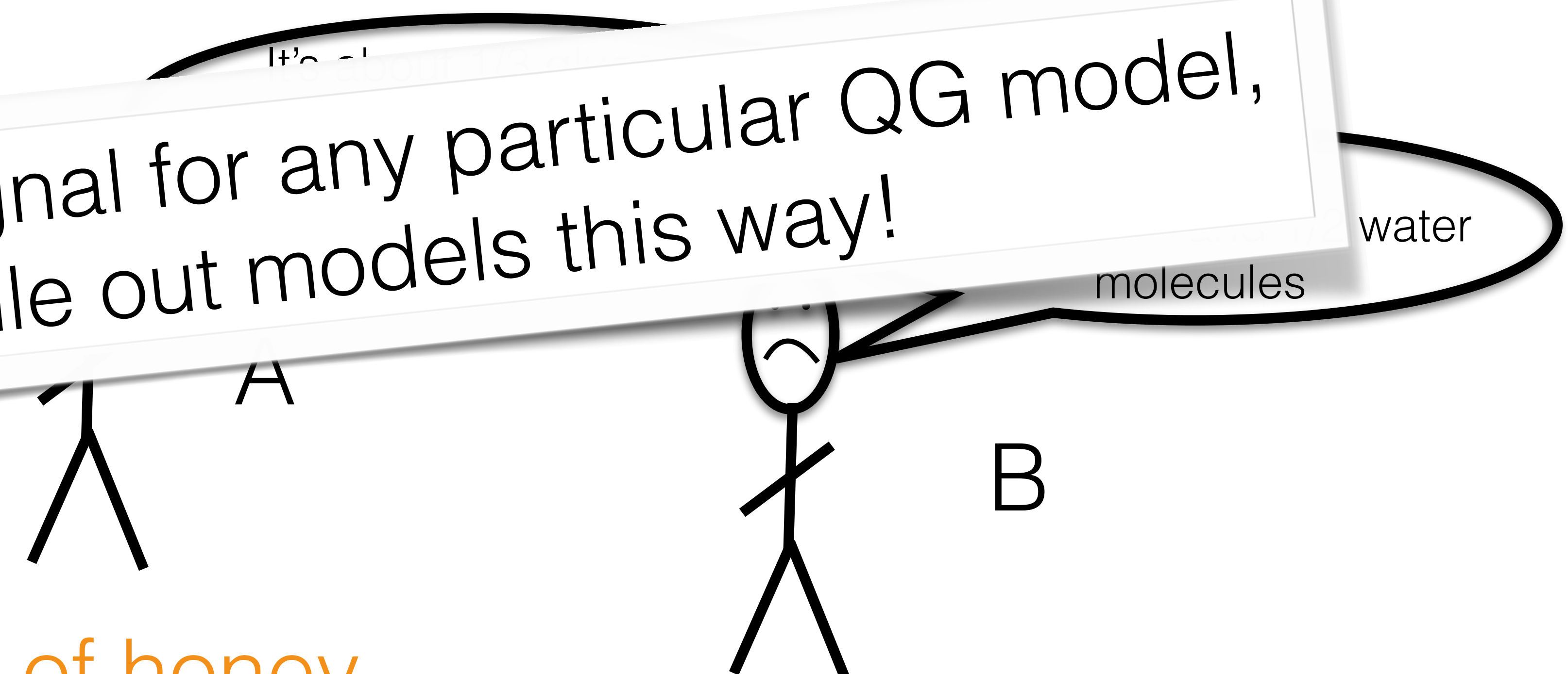

No ``smoking-gun'' signal for any particular QG model, but: could rule out models this way!

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Observational viability of quantum gravity models:

- must reduce to GR in classical limit

probes of dynamical gravity regime:
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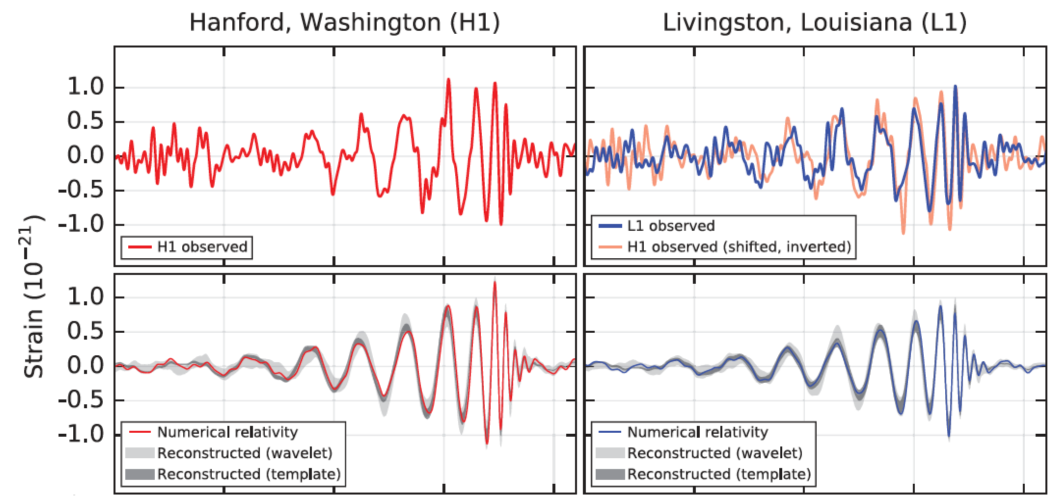

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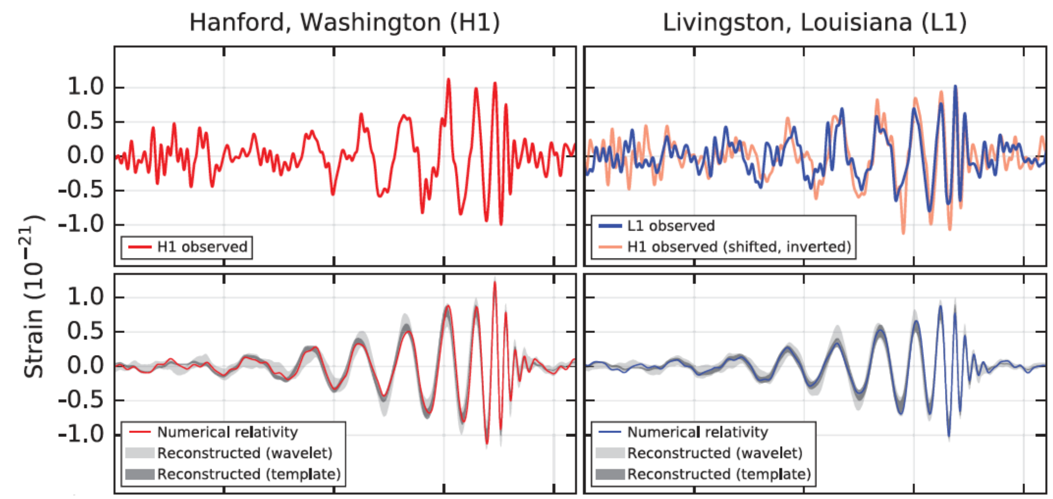

- must accommodate all observed matter degrees of freedom
  example: chiral (i.e., light) fermions

asymptotic safety ✓ (in truncation)
[A.E., Gies '11; Meibohm, Pawlowski '15]

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causal sets: fermions ???

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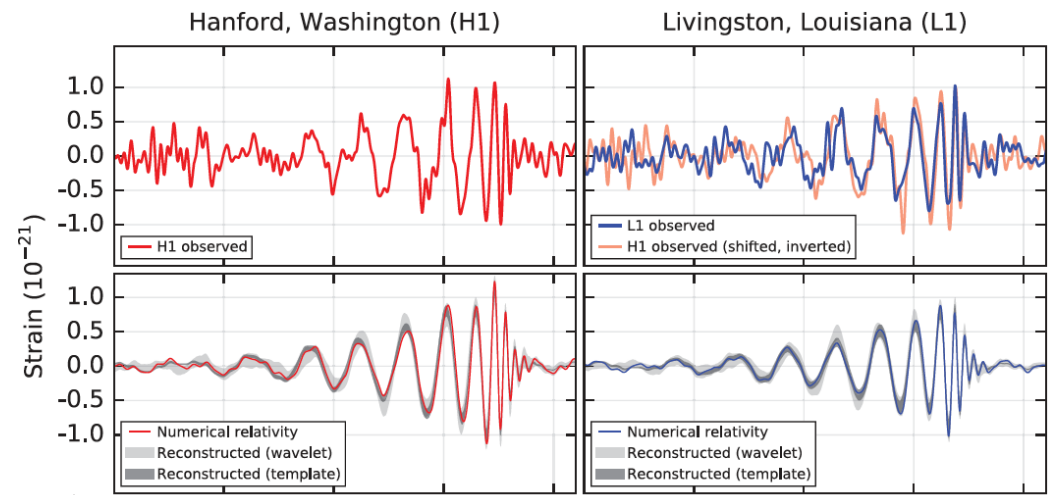

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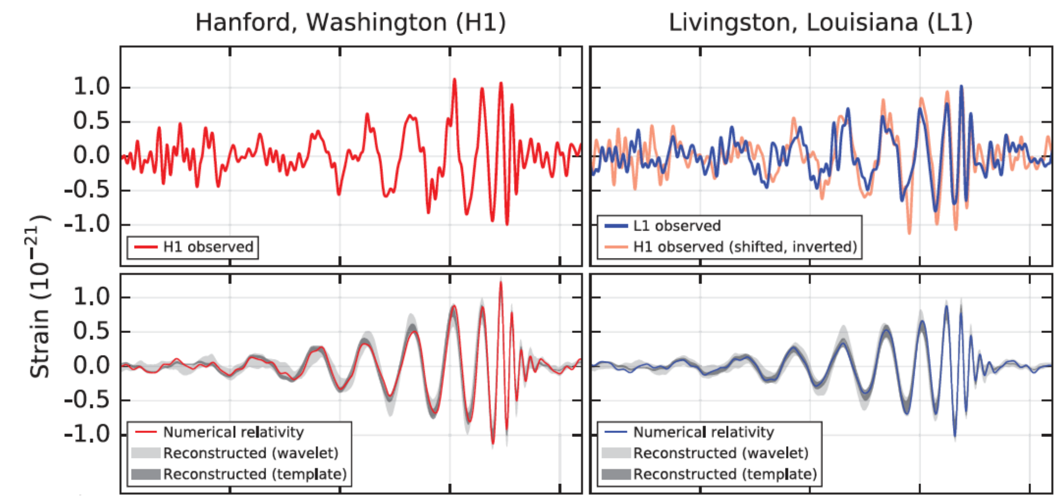

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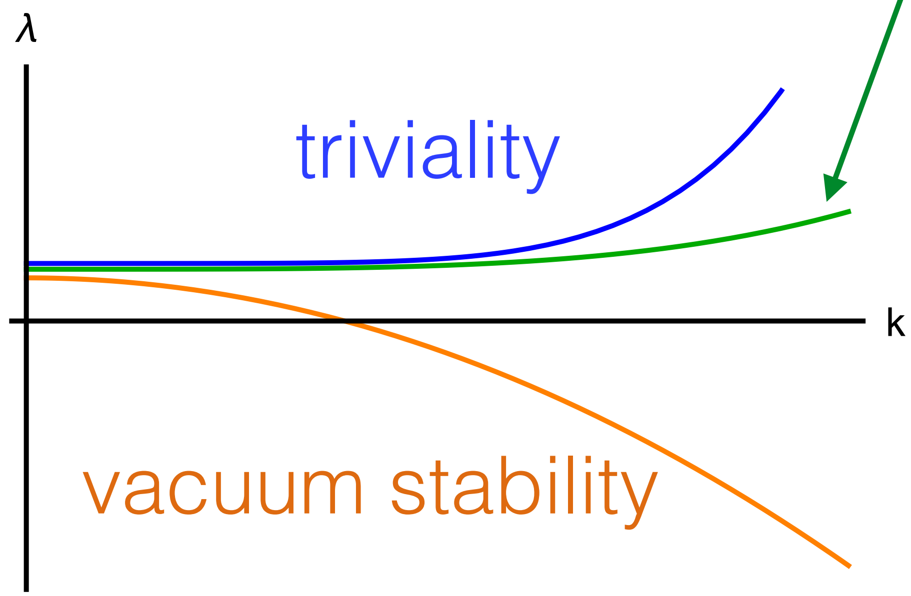
→ Higgs discovery: Standard Model consistent up to high scales

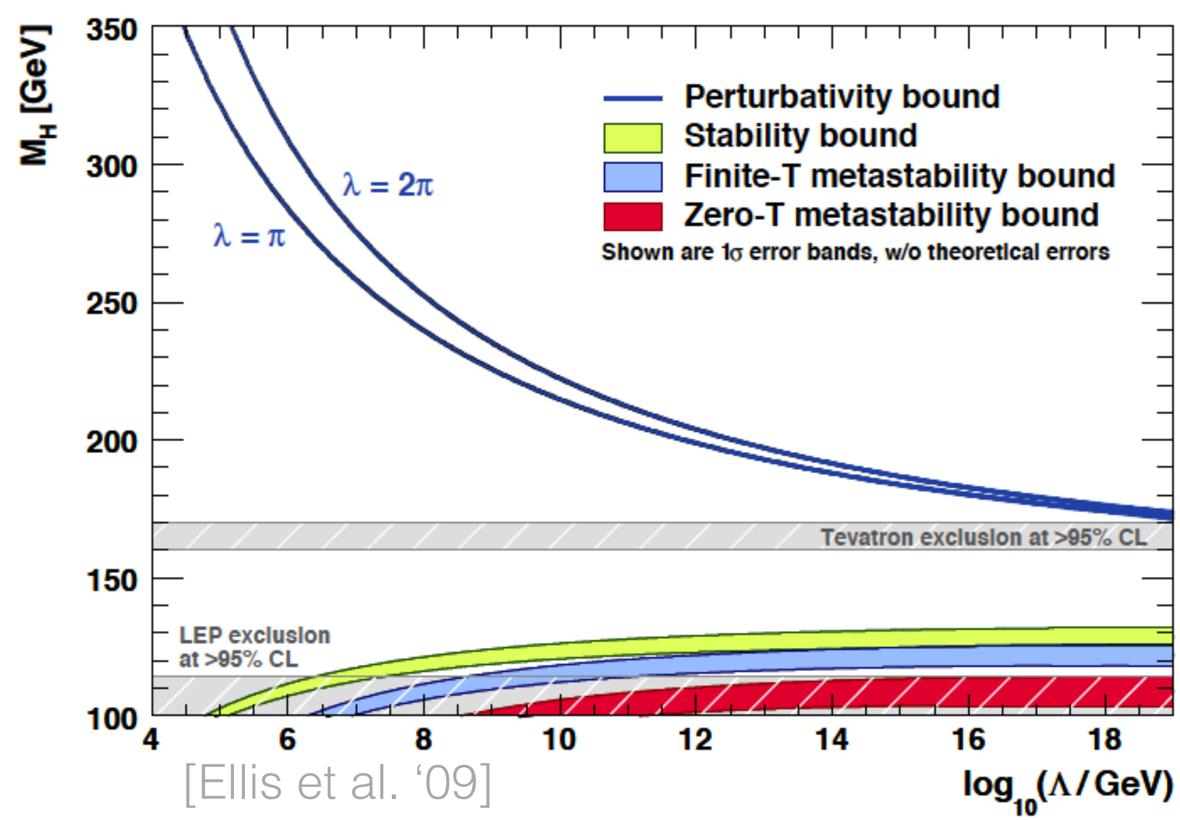
Implications of the Higgs discovery

only for narrow window of values of **Higgs masses** can we reach high scales without requiring new physics

$$M_H = \lambda \cdot 246\,\mathrm{GeV}$$

$$V[H] = \lambda\, H^4$$





[Ellis et al. '09]

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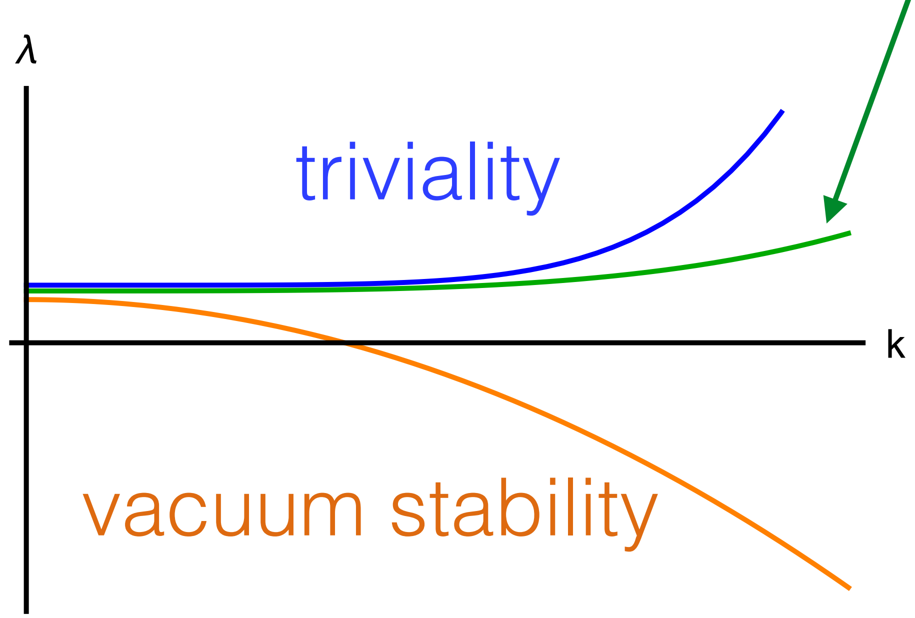
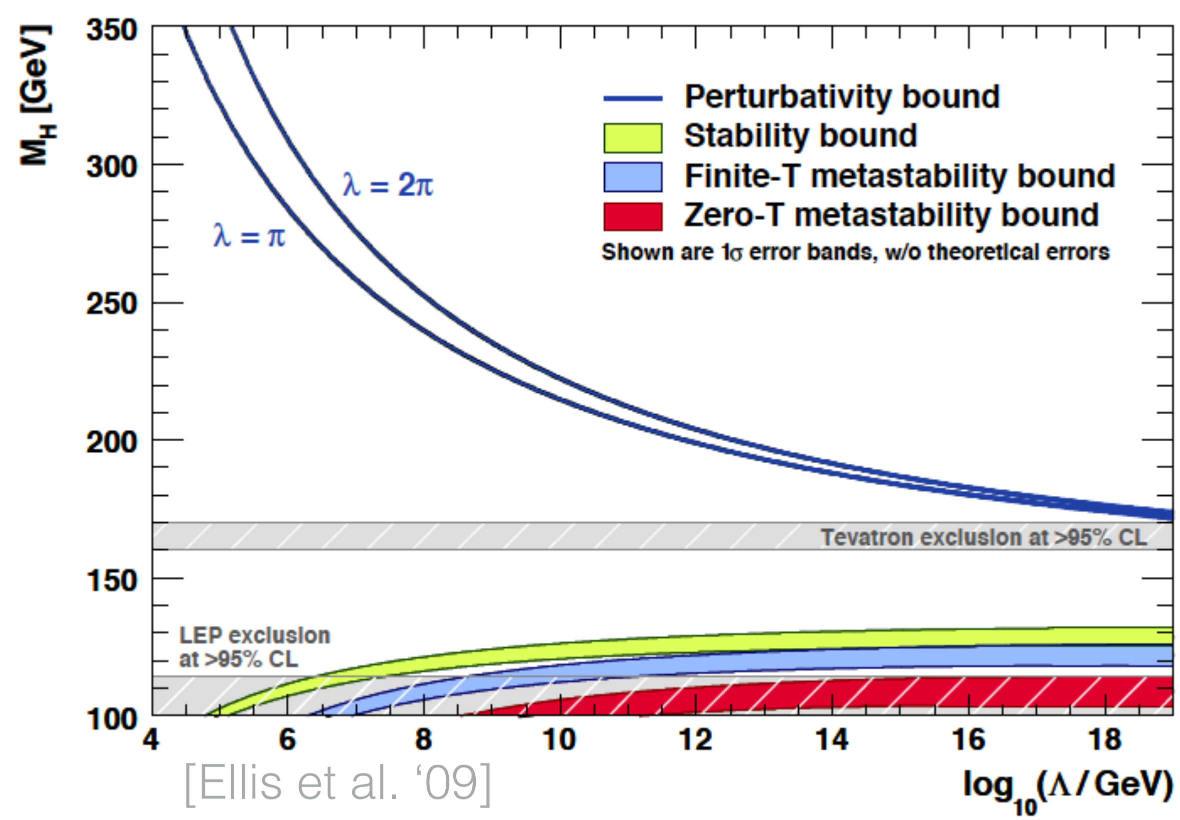
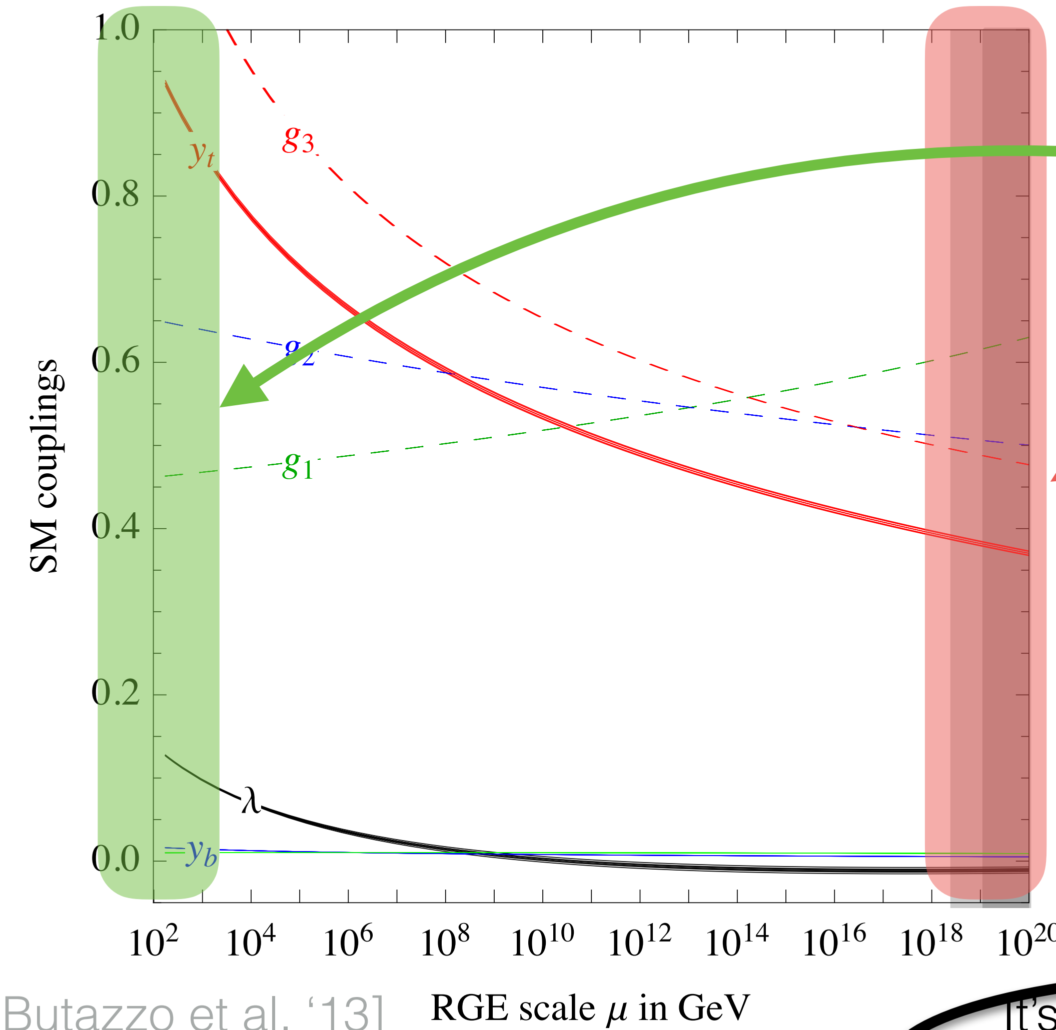




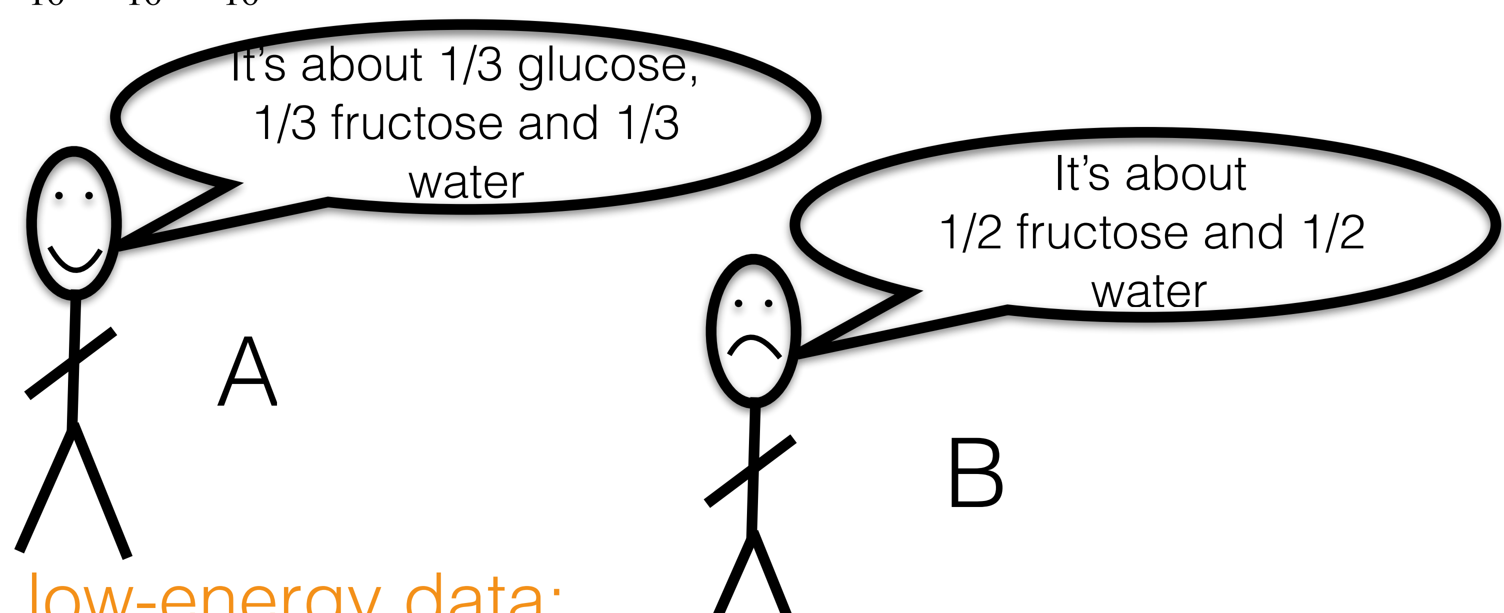
→ Does gravity provide UV completion for the SM?

A window into Planck-scale physics at the electroweak scale



low-energy data
constrains
high-energy physics

[Butazzo et al. '13]



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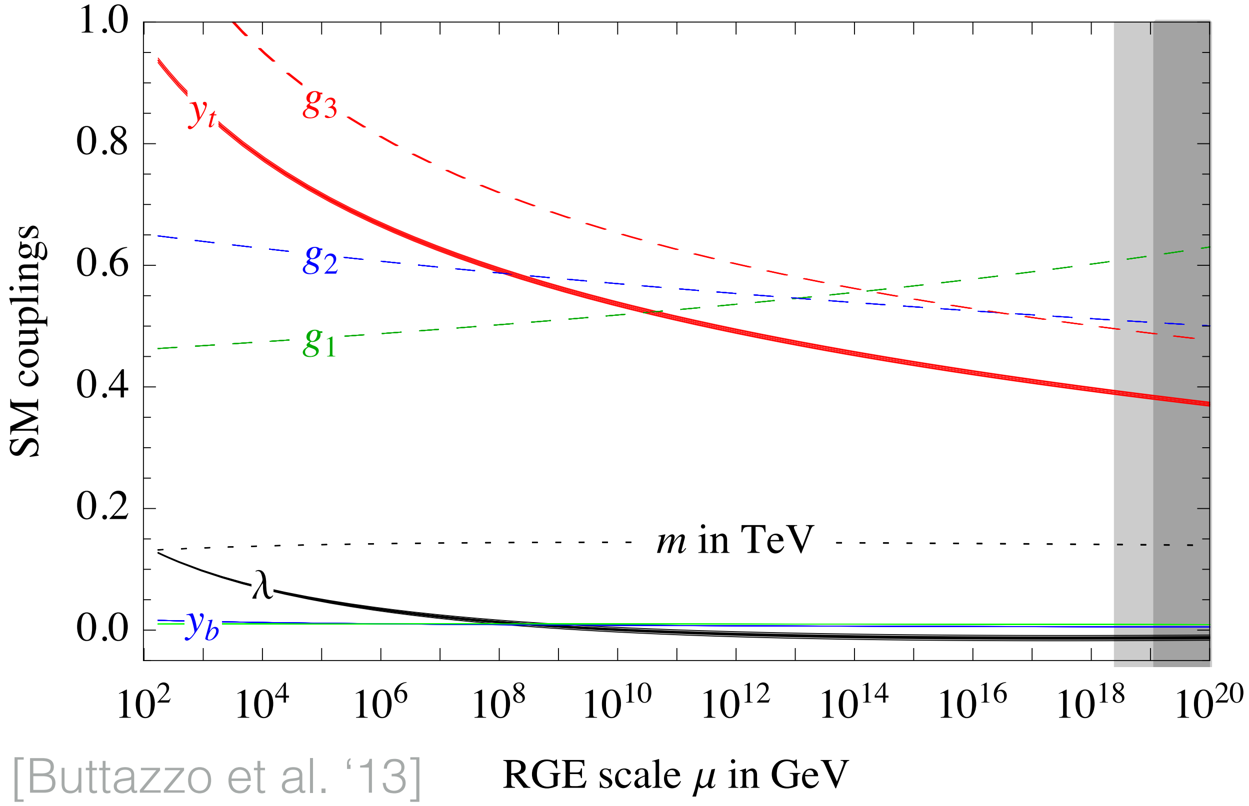
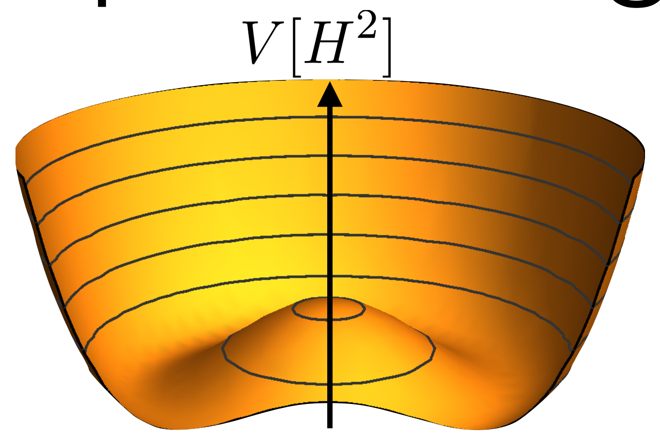
Higgs sector & quantum gravity



[Buttazzo et al. '13]



$$\Gamma_k = \ldots + m_h^2 H^2 + \lambda H^4 + \sum_q y_q H \bar{q}_R q_L + \ldots$$

$$y_t(M_{\rm Pl}) \approx 0.4 \to M_{\rm top} \approx 173\,\mathrm{GeV}$$

$$y_b(M_{\rm Pl}) \approx 0 \;\to M_{\rm bottom} \approx 4\,\mathrm{GeV}$$

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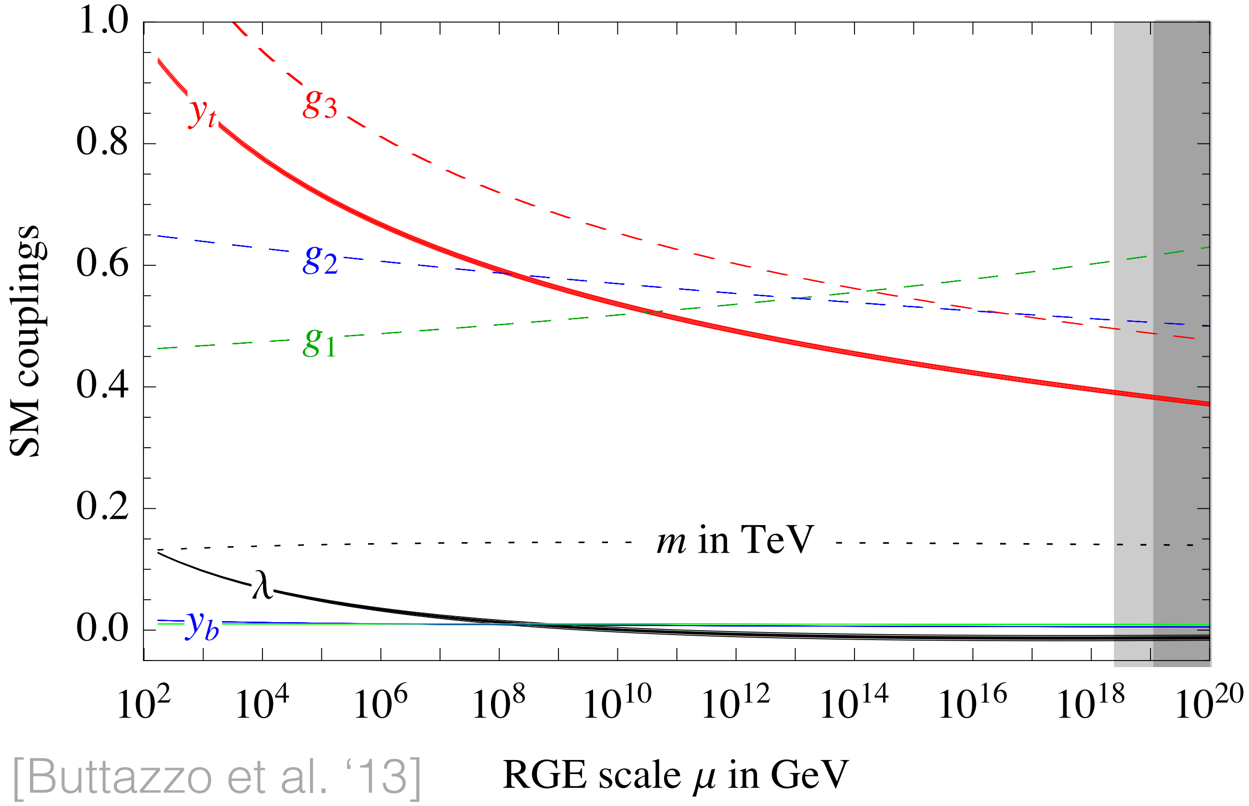

[Buttazzo et al. '13]

assume:
no new physics below M_{Planck}

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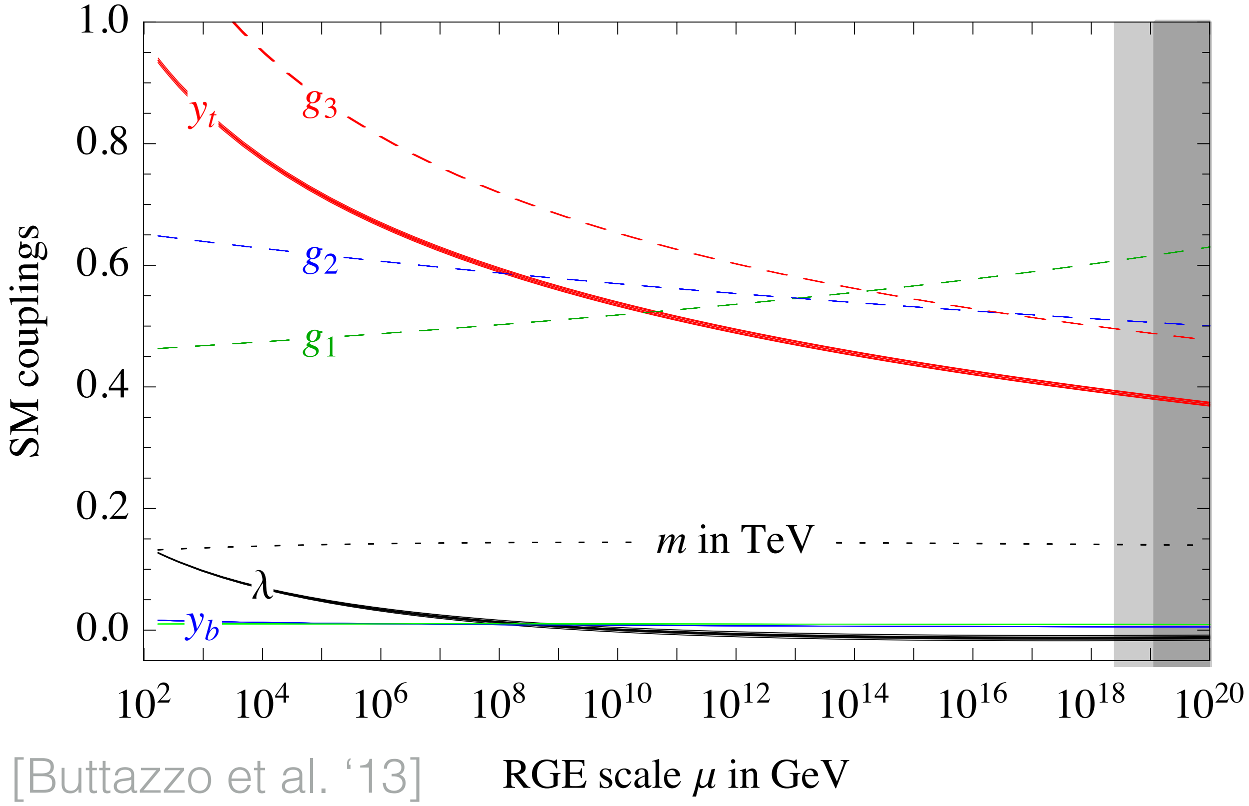

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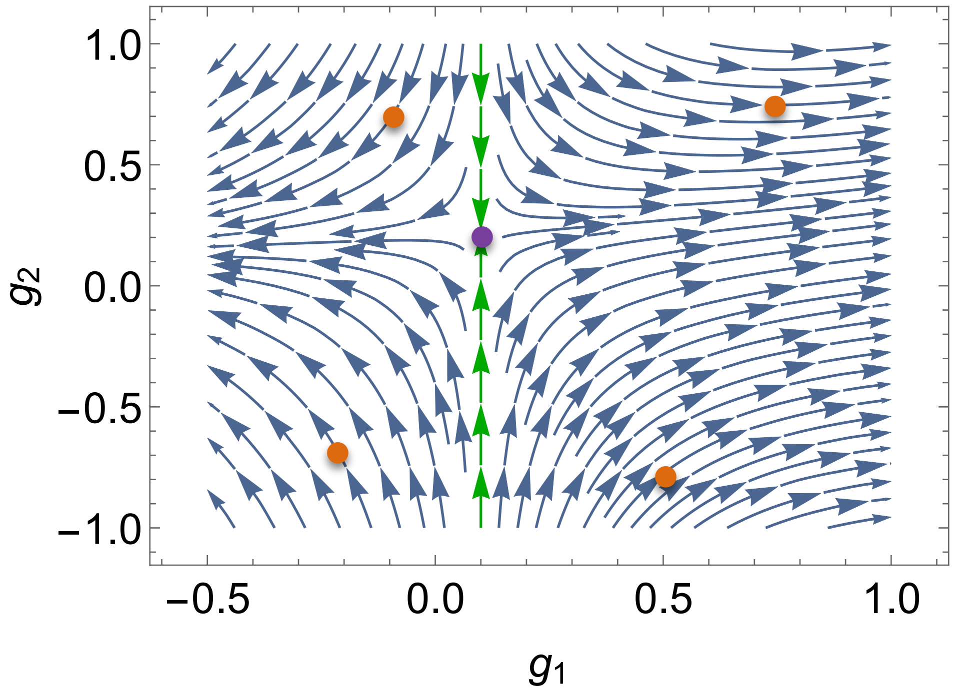

g_2: UV- attractive (relevant):
any value can be reached in IR

g_1: UV- repulsive (irrelevant):
IR-value fixed

→ Irrelevant couplings in the Higgs sector could allow prediction

Yukawa coupling in quantum gravity

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toy model of the Higgs-Yukawa sector coupled to gravity:

$$\Gamma_k = \frac{Z_\phi}{2}\int d^4x\sqrt{g}\,g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi + i\,Z_\psi\int d^4x\sqrt{g}\bar{\psi}\slashed{\nabla}\psi + i\,y\int d^4x\sqrt{g}\phi\bar{\psi}\psi$$

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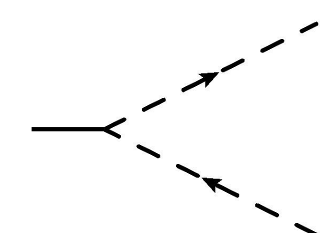
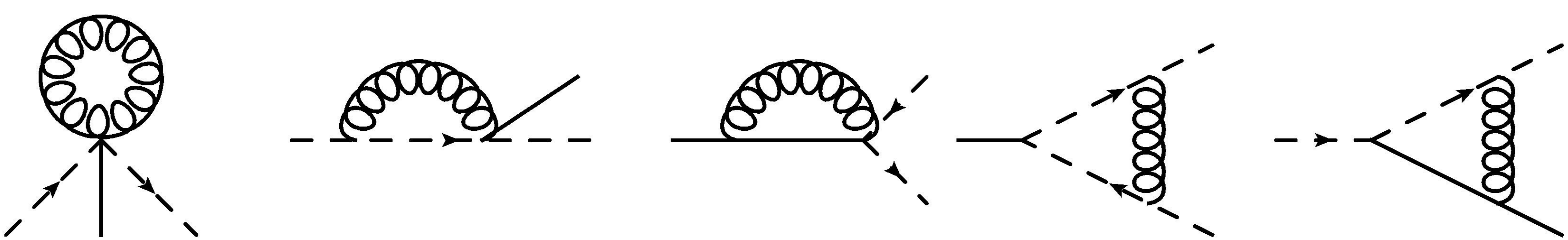
A.E., A. Held, J. Pawlowski ‘16

see also
Zanusso, Zambelli, Vacca, Percacci, ’09
Oda, Yamada ‘15

quantum-gravity effects on Yukawa coupling
(Functional Renormalization Group)





Yukawa coupling in quantum gravity

$\alpha = 1, \beta = 1$

$$\beta_y = (\eta_\phi/2 + \eta_\psi)y + \frac{60 - 5\eta_\phi - 6\eta_\psi}{480\pi^2} y^3 + G\, y\, \frac{32 + \eta_\psi}{10\pi}$$

$$\beta_G = 2G - G^2 \frac{43}{6\pi} + ...$$

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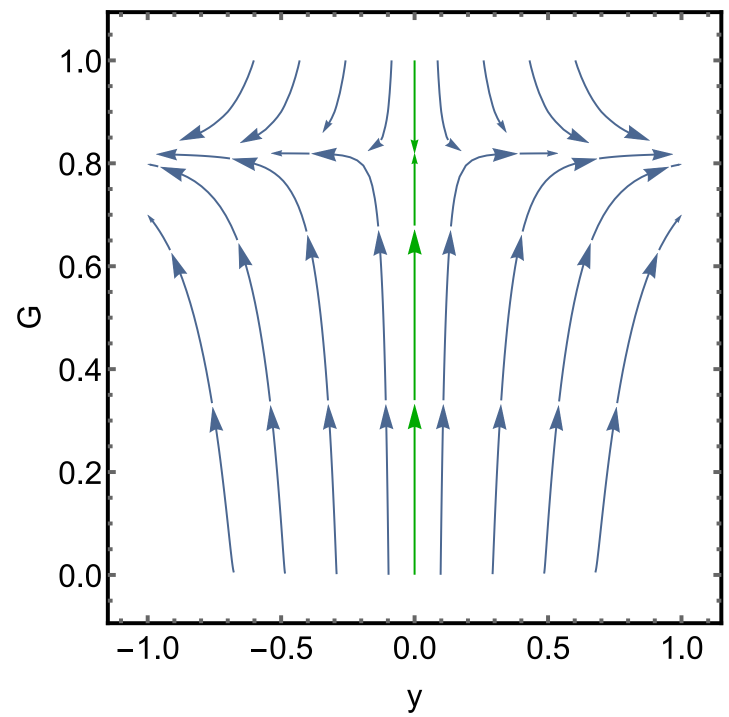

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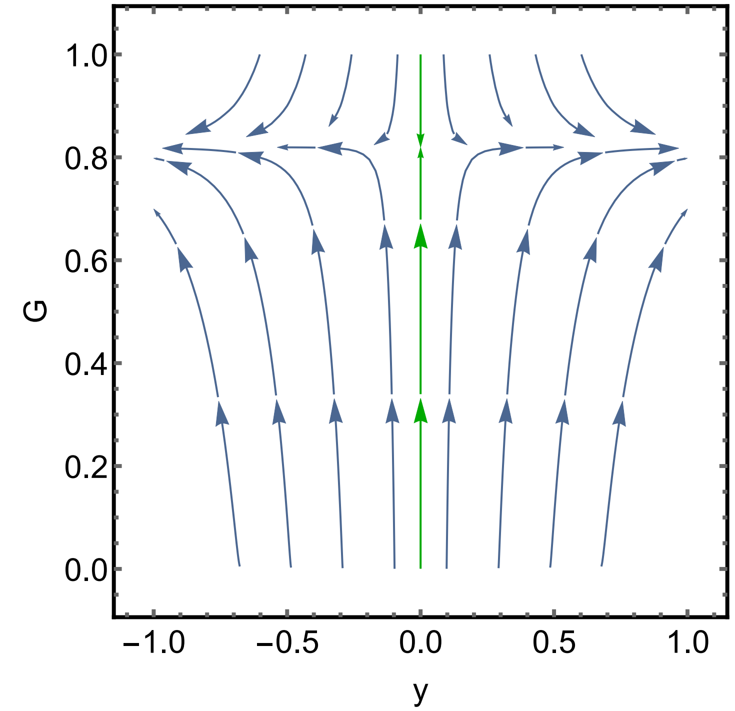

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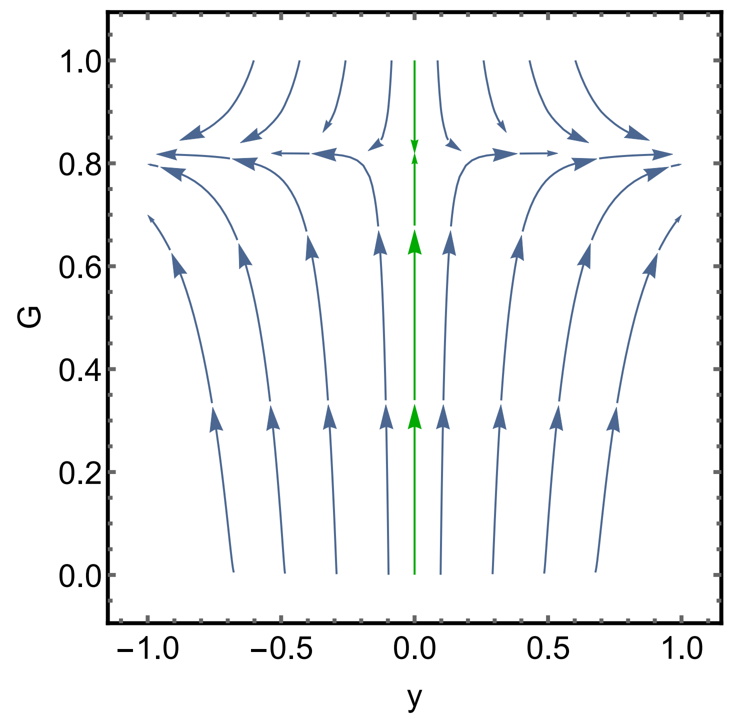

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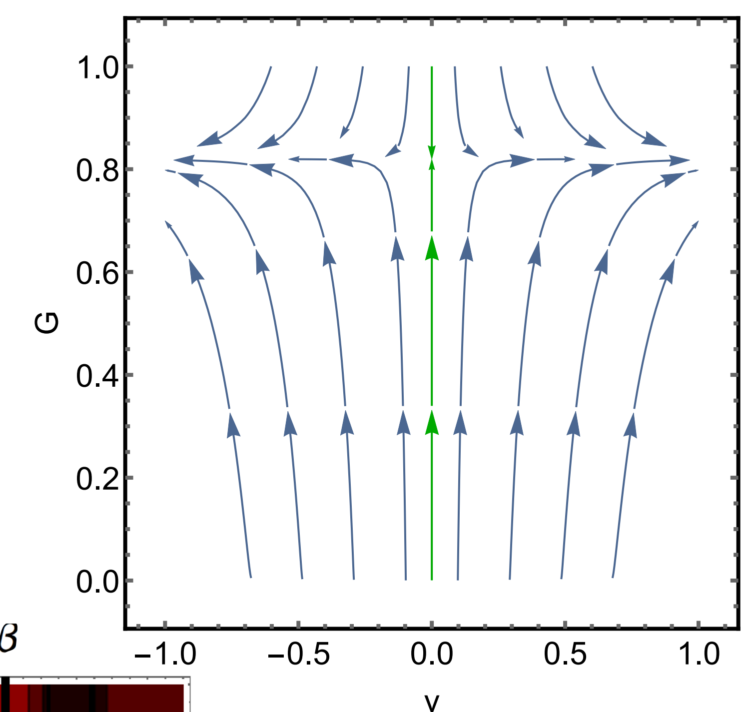

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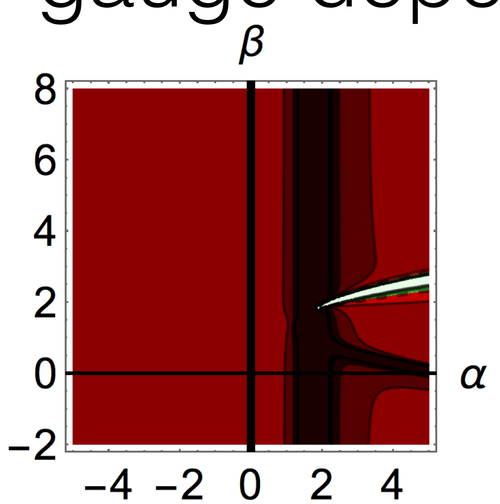
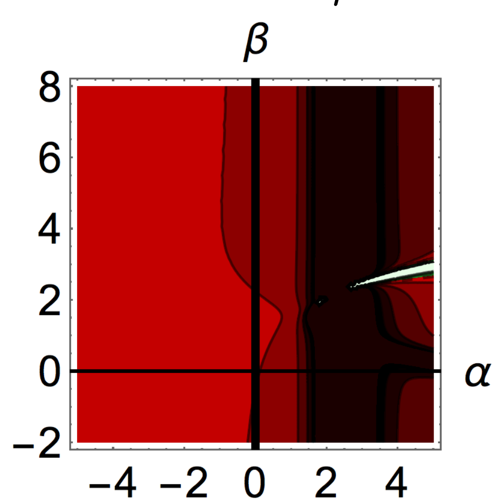
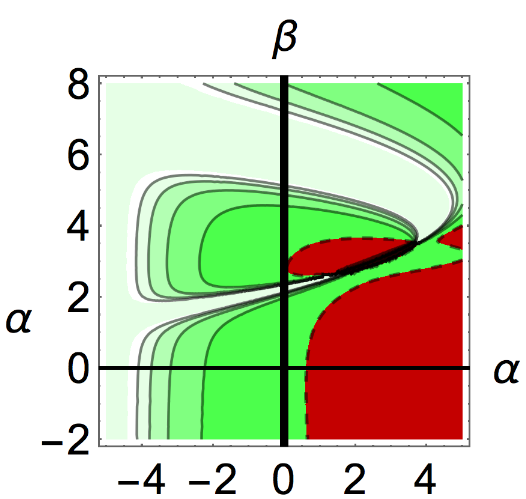
gauge dependence: $F_\mu = \bar{D}_\nu h^\nu_\mu - \frac{1+\beta}{4} \bar{D}_\mu h$



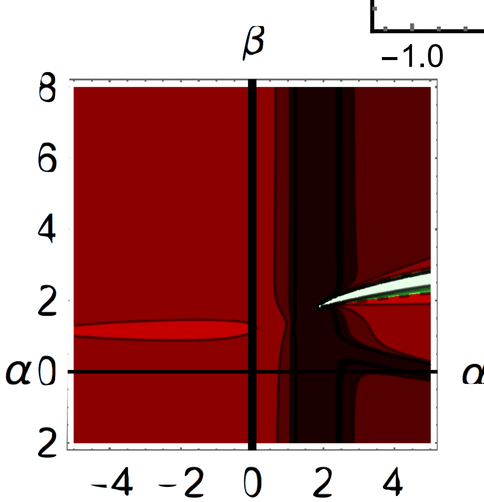
J. Meibohm, J. Pawlowski, M. Reichert '15



Becker, Reuter '14



Dona, A.E., Percacci '13



w. graviton ``mass" parameter from fluctuation calc.

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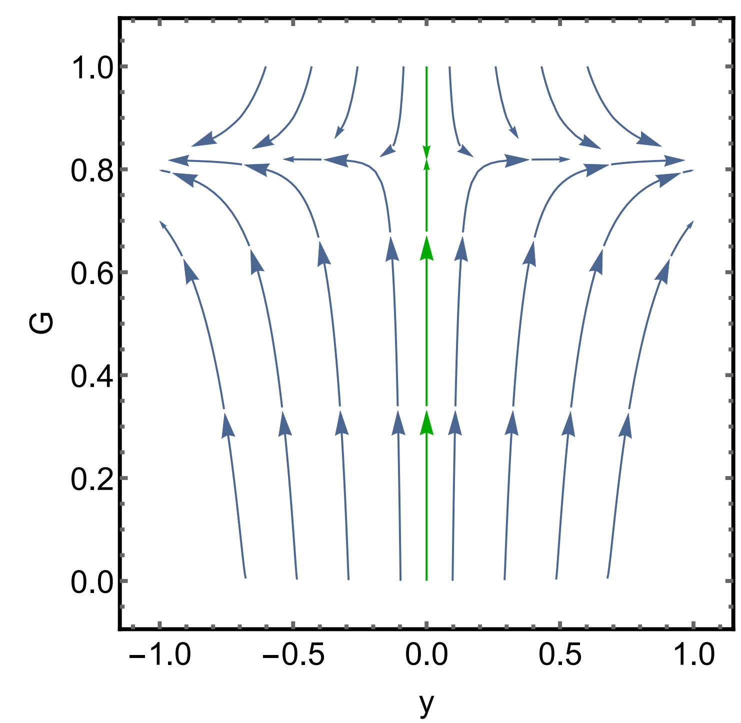

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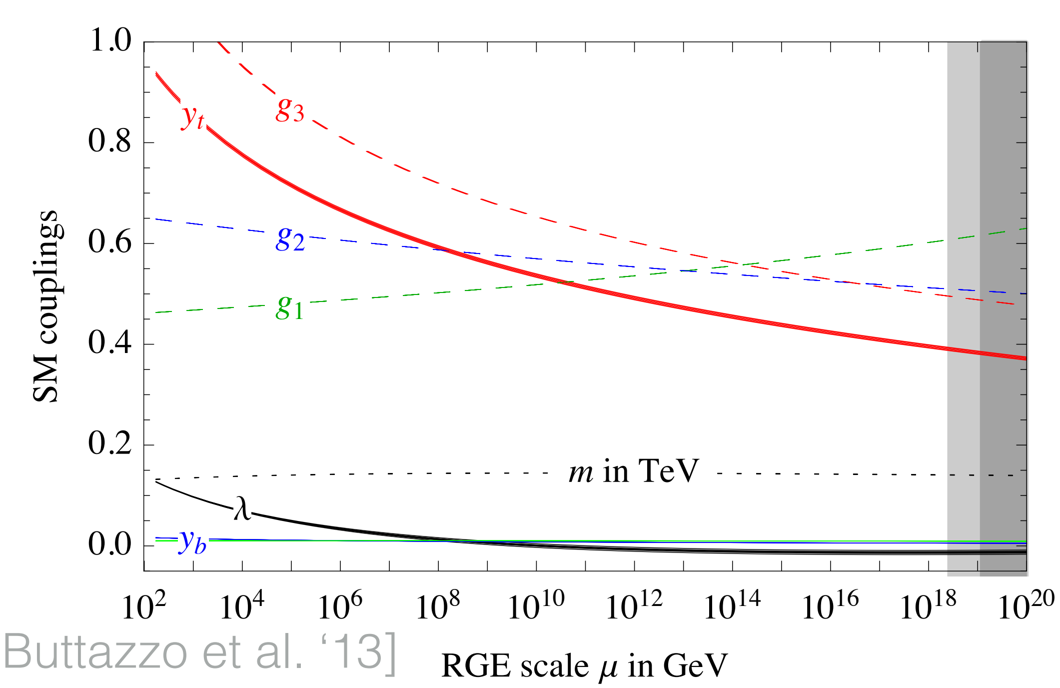

[Buttazzo et al. '13]

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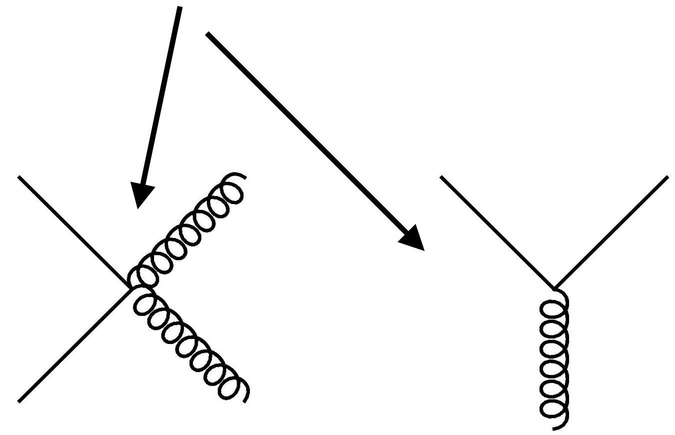

matter-gravity interaction
vertices from kinetic term

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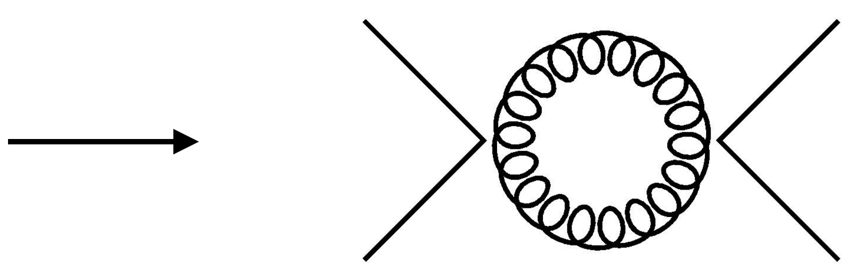

generate new momentum-dependent
matter self-interactions

A.E., H. Gies '11 | A.E. '12

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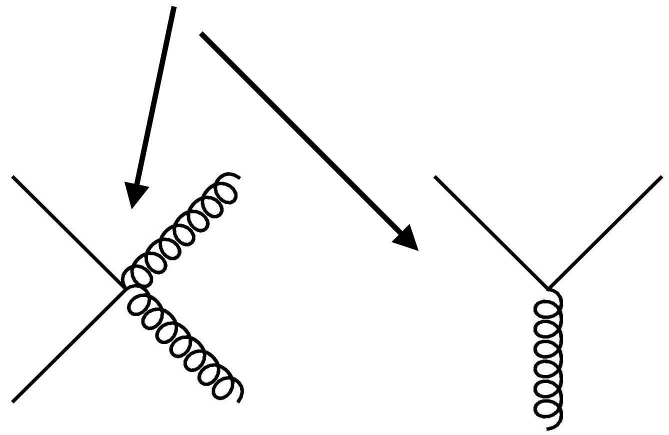

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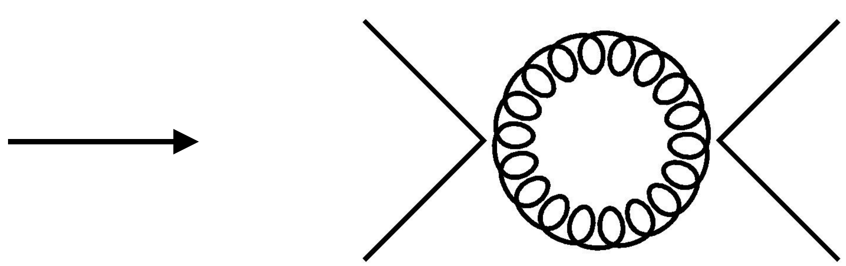

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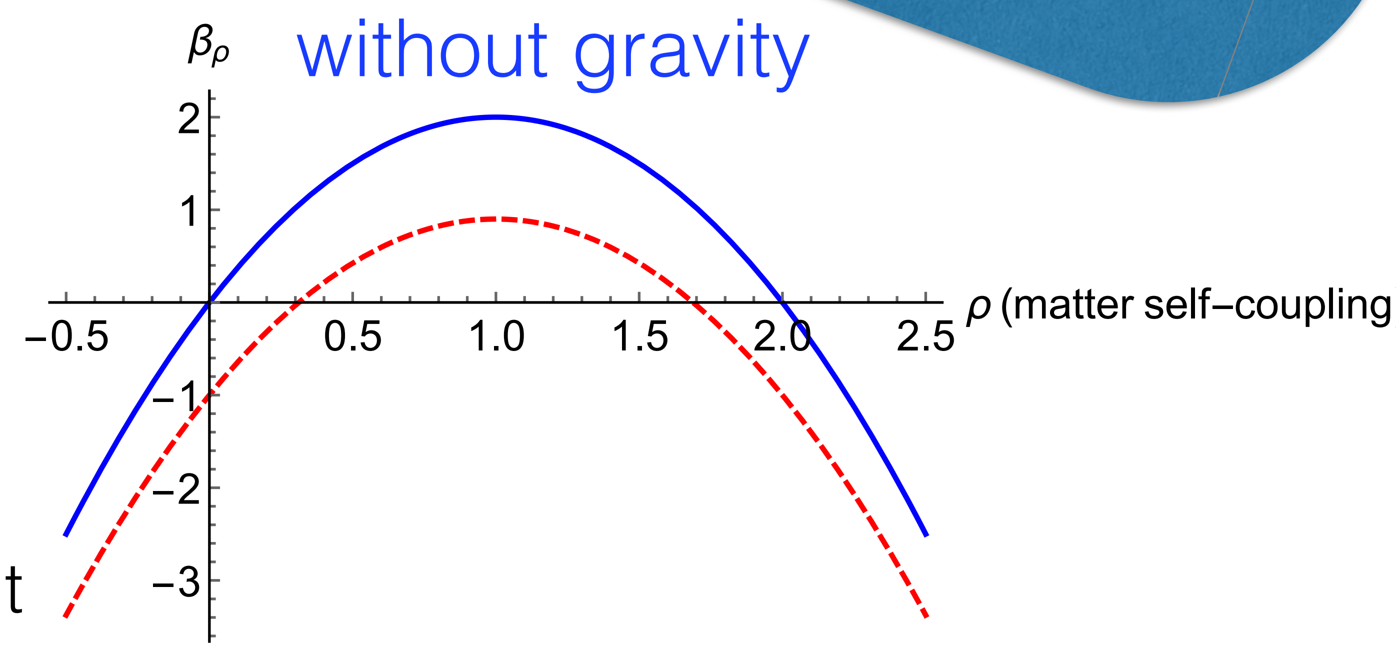

with gravity: interacting at fixed point

A.E., H. Gies '11 A.E. '12

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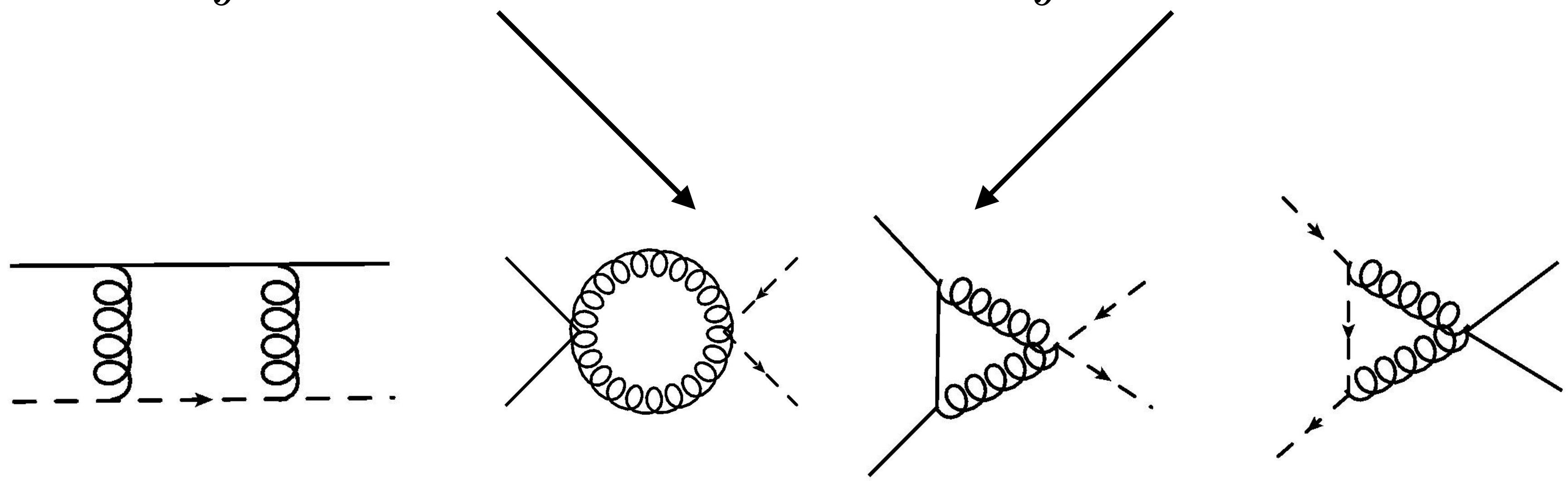

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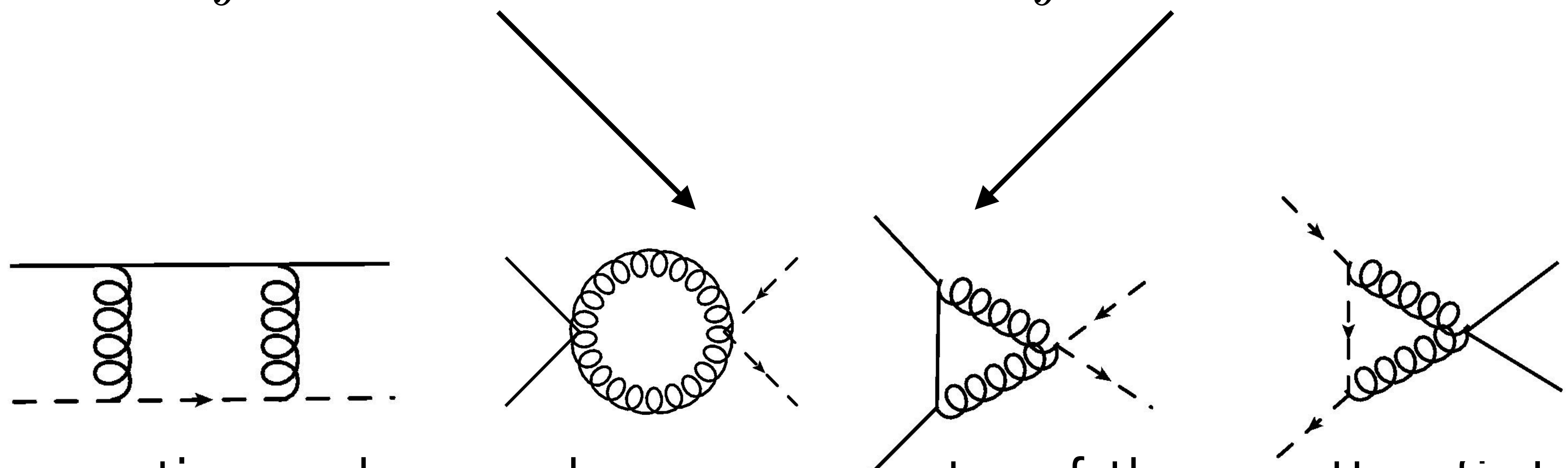
A.E., A. Held, J. Pawlowski '16



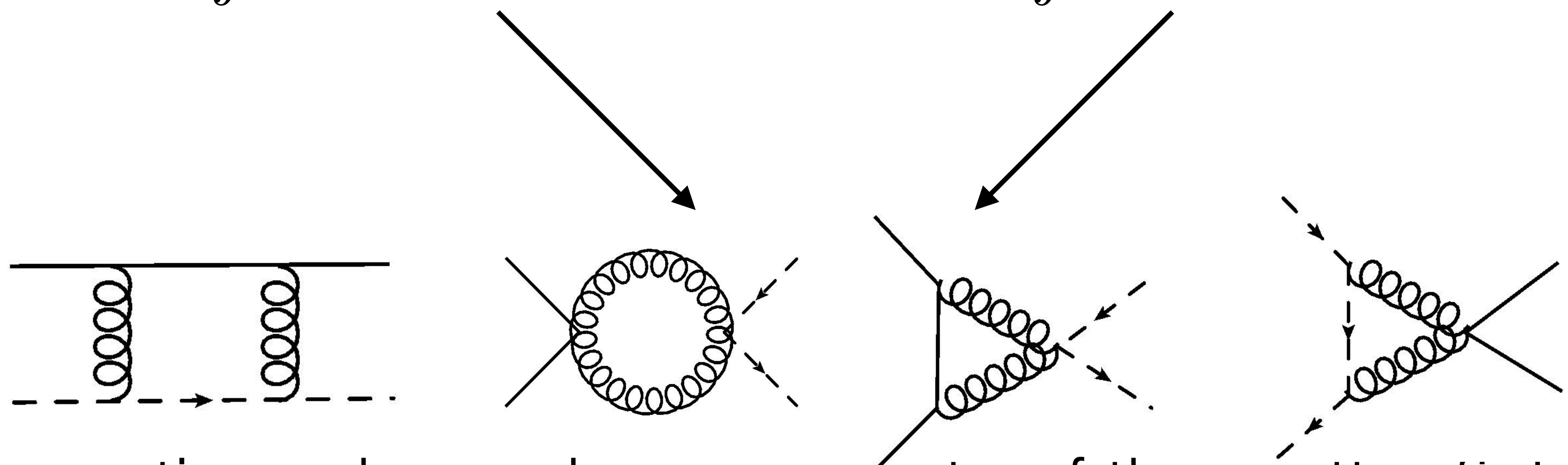
vertices depend on momenta of the matter fields:

$$\frac{\mathcal{X}_{1-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\nu\psi - (\nabla_\nu\bar{\psi})\gamma^\mu\psi\right)\partial_\mu\phi\partial^\nu\phi\right] + \frac{\mathcal{X}_{2-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\mu\psi - (\nabla_\mu\bar{\psi})\gamma^\mu\psi\right)\partial_\nu\phi\partial^\nu\phi\right]$$

Beyond canonical power counting

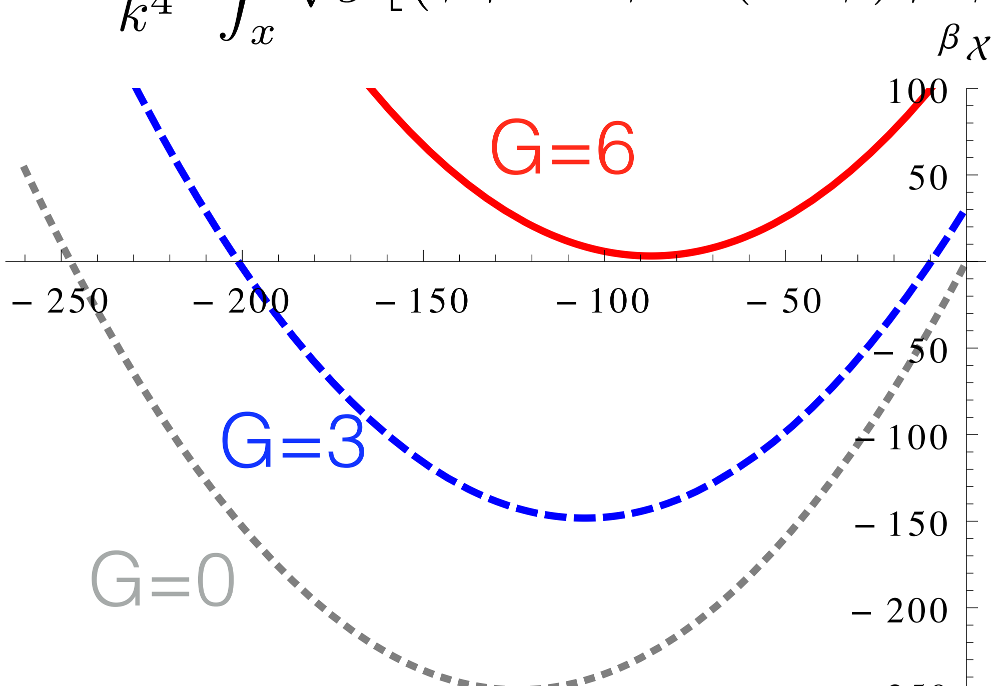
$$\Gamma_k = \frac{Z_\phi}{2}\int d^4x\sqrt{g}\,g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi + i\,Z_\psi\int d^4x\sqrt{g}\bar{\psi}\slashed{\nabla}\psi + i\,y\int d^4x\sqrt{g}\phi\bar{\psi}\psi$$

A.E., A. Held, J. Pawlowski ‘16



vertices depend on momenta of the matter fields:

$$\frac{\chi_{1-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\nu\psi-(\nabla_\nu\bar{\psi})\gamma^\mu\psi\right)\partial_\mu\phi\partial^\nu\phi\right]+\frac{\chi_{2-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\mu\psi-(\nabla_\mu\bar{\psi})\gamma^\mu\psi\right)\partial_\nu\phi\partial^\nu\phi\right]$$



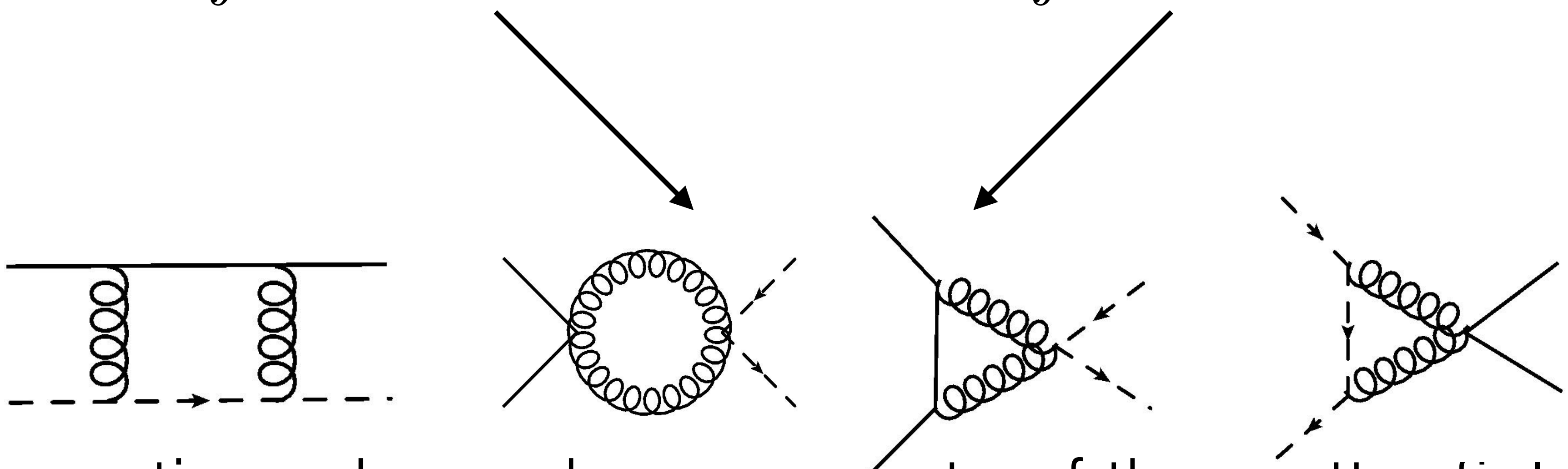
$$\chi = \frac{1}{\sqrt{2}}(\chi_{1-}+\chi_{2-})$$

strong gravity fluctuations appear incompatible with existence of fixed point in matter sector

Beyond canonical power counting

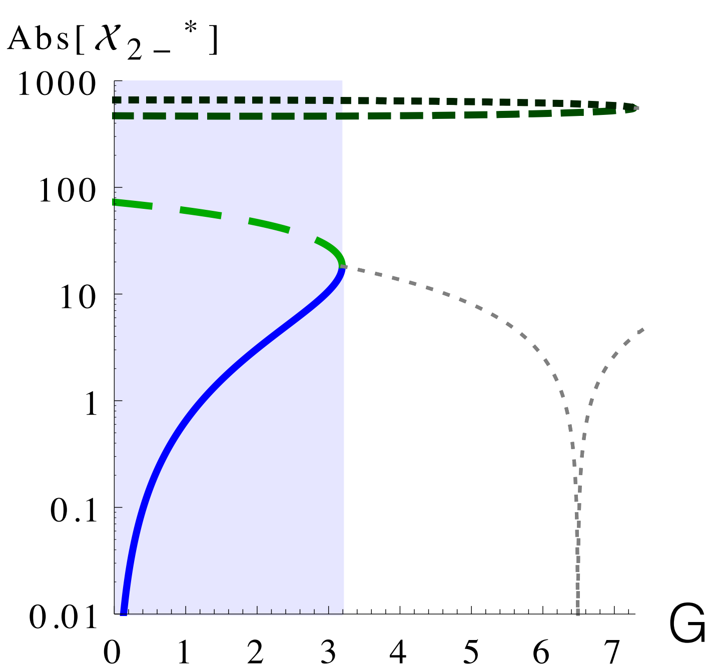
$$\Gamma_k = \frac{Z_\phi}{2}\int d^4x\sqrt{g}\,g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi + i\,Z_\psi\int d^4x\sqrt{g}\bar{\psi}\slashed{\nabla}\psi + i\,y\int d^4x\sqrt{g}\phi\bar{\psi}\psi$$

A.E., A. Held, J. Pawlowski ‘16



vertices depend on momenta of the matter fields:

$$\frac{\mathcal{X}_{1-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\nu\psi-(\nabla_\nu\bar{\psi})\gamma^\mu\psi\right)\partial_\mu\phi\partial^\nu\phi\right]+\frac{\mathcal{X}_{2-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\mu\psi-(\nabla_\mu\bar{\psi})\gamma^\mu\psi\right)\partial_\nu\phi\partial^\nu\phi\right]$$

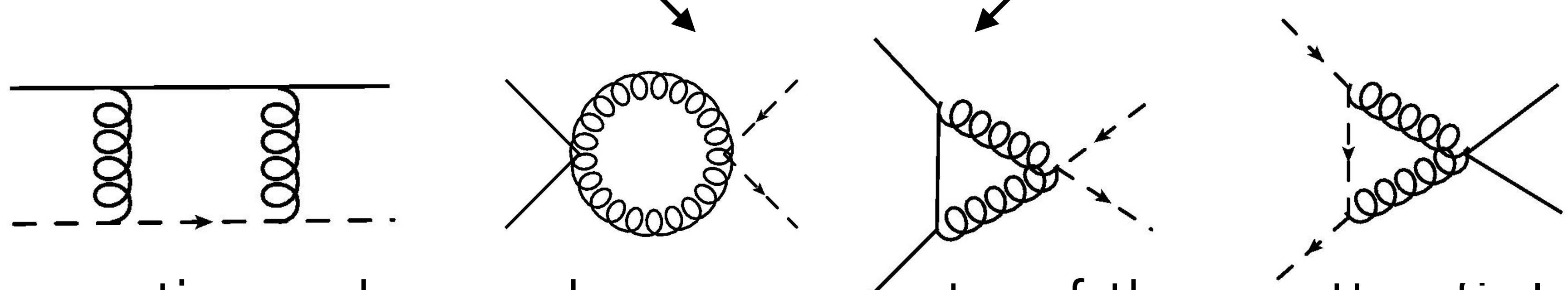


strong gravity fluctuations appear incompatible with existence of fixed point in matter sector

Beyond canonical power counting

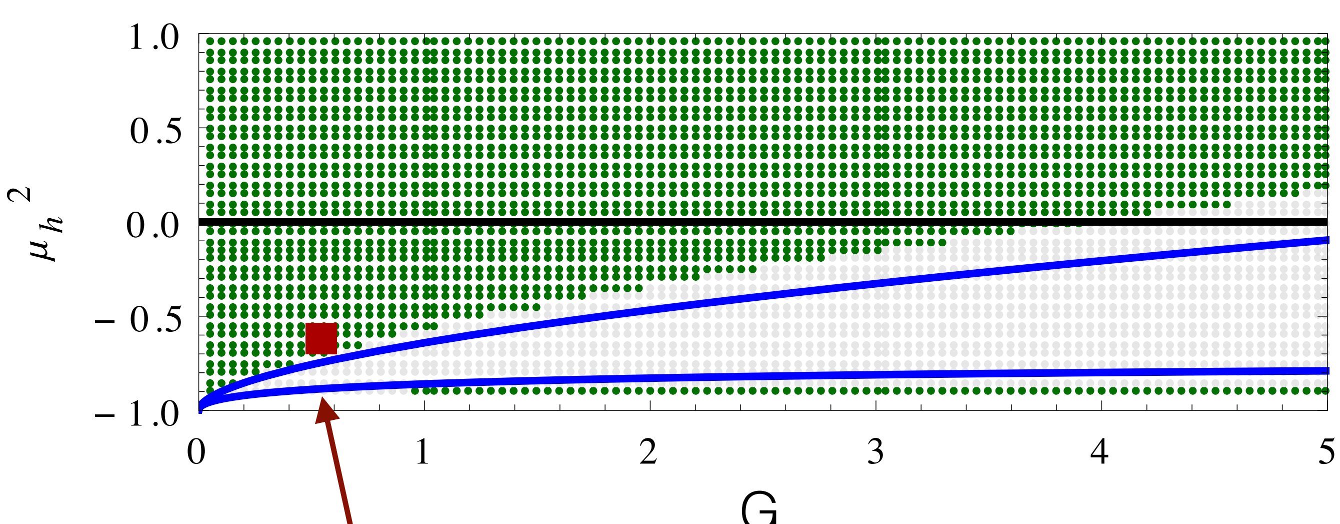
$$\Gamma_k = \frac{Z_\phi}{2}\int d^4x\sqrt{g}\,g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi + i\,Z_\psi\int d^4x\sqrt{g}\bar{\psi}\not{\nabla}\psi + i\,y\int d^4x\sqrt{g}\phi\bar{\psi}\psi$$

A.E., A. Held, J. Pawlowski ‘16



vertices depend on momenta of the matter fields:

$$\frac{\mathcal{X}_{1-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\nu\psi-(\nabla_\nu\bar{\psi})\gamma^\mu\psi\right)\partial_\mu\phi\partial^\nu\phi\right]+\frac{\mathcal{X}_{2-}}{k^4}\int_x\sqrt{g}\left[\left(\bar{\psi}\gamma^\mu\nabla_\mu\psi-(\nabla_\mu\bar{\psi})\gamma^\mu\psi\right)\partial_\nu\phi\partial^\nu\phi\right]$$



fixed-point values (w/o $\eta_{\psi,\phi}$ from $\mathcal{X}_{i-}$)

Meibohm, Pawlowksi, Reichert ‘15

strong gravity fluctuations appear incompatible with existence of fixed point in matter sector

but: critical interaction strength not exceeded (within truncation)

$\rightarrow$ joint fixed point

Conclusions

- properties of the matter sector offer observational consistency tests for quantum gravity

- microscopic model must admit all observed properties of matter (values of masses etc)

- toy model of Higgs sector coupled to asymptotically safe quantum gravity: $\rightarrow y(M_{\mathrm{Pl}}) \approx 0$

  $\rightarrow$ gravity does not exceed critical strength for fixed-point annihilation in Yukawa sector

  $\rightarrow$ momentum-dependent scalar-fermion interactions

Outlook: Realistic Yukawa sector (top-bottom asymmetry)