Induced scalar interactions in quantum gravity

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outline

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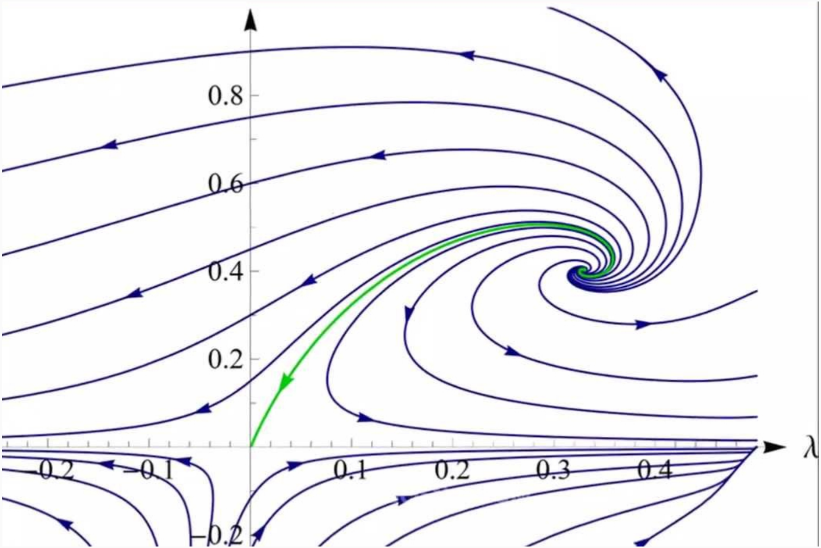
1. Asymptotic Safety of gravity and matter
2. A priori argument for interactions at a fixed point
3. Computation details (overview)
4. Results on interacting gravity-scalar fixed point

Reference: 1710.03005

Asymptotic Safety program

Figure: RG flow diagram in Einstein-Hilbert truncation



State of the art

$$k\frac{d}{dk}\Gamma_k^{(1L)} = \frac{1}{2}\mathrm{tr}\left[\frac{\delta^2 S}{\delta\phi\delta\phi} + R_k\right]^{-1} k\frac{d}{dk}R_k$$

- Functional truncations, e.g. $\Gamma_k \sim \int_x f(R)$
- Vertex expansions and bimetric truncations
- (Background independence)
- gravity + SM

Including matter (en route to gravity+SM)

Some of the most important questions are:

- Can (too much) matter destabilize gravitational FP? (maybe)
- Does asymptotic freedom survive inclusion of gravity? (yes)
- Can gravity cure U(1) Landau poles? (yes)
- Could we have predictive quantum gravity? (yes)
- Can all matter be non-interacting at the FP? (no)

A priori argument against non-interacting matter

Matter interactions at the fixed point

Central idea

Interactions with kinetic term symmetries are gravity-induced

- Consider an interaction term with 2n matter fields
- Provided its beta function has a contribution which is not proportional to the 2n matter coupling itself...
- ...beta function cannot be set to zero by switching off the coupling!

Matter interactions at the fixed point

Central idea

Interactions with kinetic term symmetries are gravity-induced

- Assume the interaction term is compatible with the symmetries of the kinetic term
- Expanding kinetic term to second order in gravitons one obtains an $h - h - \phi - \phi$ vertex
- Using these vertices one can construct 1-loop diagram with n internal $h's$ and 2n external $\phi's$
- These are precisely contributions to the beta functions which are independent of the vertices themselves!

Matter interactions at the fixed point

Central idea

Interactions with kinetic term symmetries are gravity-induced

- Gravity-induced matter interactions in the UV are unavoidable

Aspects of the computation

diff-invariant action

- Start with the Einstein-Hilbert action, $\mathcal{L}_{EH} = \frac{1}{16\pi G}\sqrt{g}\ R$,
- minimally coupled to a scalar, $\mathcal{L}_{min} = \frac{1}{16\pi G}\sqrt{g} g^{\mu\nu}\ \partial_\mu \phi \partial_\nu \phi$
- Add a non-minimal derivative interaction to the Lagrangian:

$$\mathcal{L}_{\neg min} = \sigma \sqrt{g} R^{\mu\nu} \partial_\mu \phi \partial_\nu \phi$$

vertex expansion and relevant operators

- We work in the context of vertex expansion
- Linear split of the metric $g = \bar{g} + h = \delta + h$
- Gauge $\alpha \to \beta \to 0$ implies $h = h^{TT} + \frac{1}{4}\bar{g}h^{tr}$
- We want to follow the RG flow of the vertices

$$g_3 \; h^{TT}_{\mu\nu} \; \partial^\mu\phi\partial^\nu\phi; \;\; \sigma_3 \; \partial^2 h^{TT}_{\mu\nu} \; \partial^\mu\phi\partial^\nu\phi$$

- We also follow anomalous dimensions of TT, tr, and ϕ

discarded operators of the same mass dimension

- Terms s.a. $R^m \phi^n$ break shift symmetry of the kinetic term...
- ...so they were found to feature a Gaussian FP
- Another potentially interesting term is
- $R \, g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi$, but it vanishes for $g \to \delta$, $h \to h^{TT}$

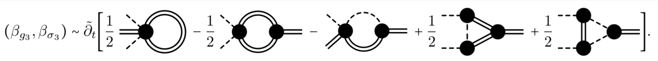
prescription for the computation

1. Do PF-expansion to get all diagrams
2. Extract vertices using xAct
3. Write code to contract vertices and do loop momenta
4. Project to get beta functions

- PF expansion:

$$STr[\frac{1}{H}\dot{R}_k] \equiv \tilde{\partial}_t STr \log H \equiv \tilde{\partial}_t STr \log(P+F) \equiv \tilde{\partial}_t STr \log P(1+\frac{F}{P}) \simeq \tilde{\partial}_t STr \sum_{m=1}^{\infty} \frac{(-)^{m+1}}{m}(\frac{F}{P})^m$$

- Our computation consists in evaluating diagrams s.a.



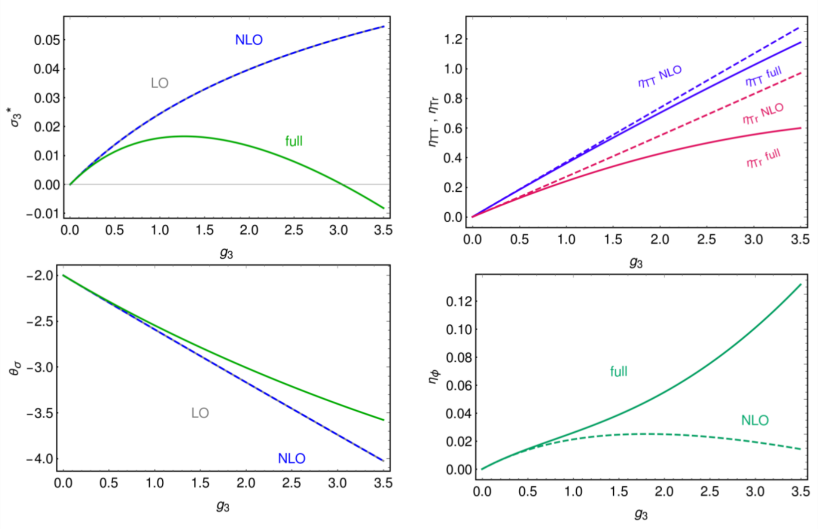
- This is achieved using own code based on Mathematica+xAct
- For a double-check we wrote two entirely independent codes
- 1^{st}: Real space, no TT-decomp., generic α, β, generic split
- 2^{nd}: Momentum space, TT-decomp., $\alpha = \beta = 0$, linear split

some conventions, notation, etc..

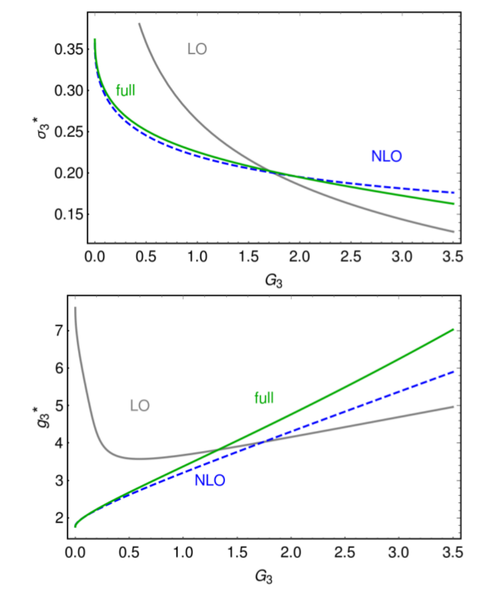
- Ways to treat anomalous dim's $\rightarrow$ "LO", "NLO" and "full"
- h-ϕ-ϕ Newton coupling, g_3, dynamically tracked
- h-h-h Newton coupling, G_3, not tracked dynamically
- higher "avatars" id'd with lower analogs (e.g. $g_5 \rightarrow g_4 \rightarrow g_3$)

Some results

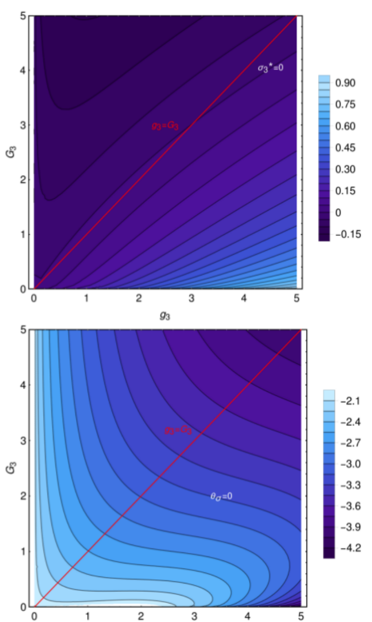
σ_3 as a function of $g_3 (\simeq G_3)$



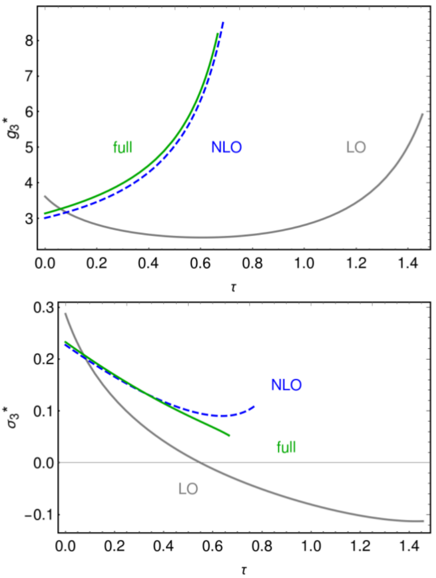
σ_3 and g_3 as functions of G_3



σ_3 as a function of g_3 and $G_3 (\neq g_3)$



instability of the exp parametrization



recap & outlook

- Contemporary Asymptotic Safety research is bringing quantum gravity in contact with the physical world!
- To quantitatively explain/predict data we need to make our truncations more realistic!
- Among other things this means including matter interactions

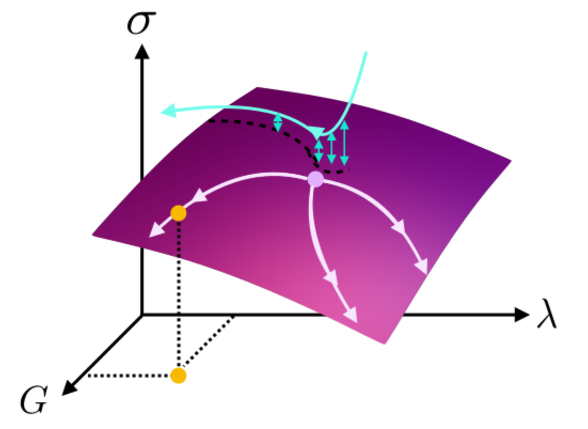
will be crucial

Thank you!

some additional figures

system & order	g_3^*	σ_3^*	θ_1	θ_2	η_{TT}	η_{tr}	η_ϕ
$g_3@LO$	2.51	-	2	-	0	0	0
$g_3, \sigma_3@LO$	3.61	.29	1.88	-2.05	0	0	0
$g_3@NLO$	3.01	-	3.11	-	.34	.14	.11
$g_3, \sigma_3@NLO$	3.01	.23	2.96	-2.77	.27	.29	-.26
$g_3@full$	3.17	-	3.07	-	.33	.12	.11
$g_3, \sigma_3@full$	3.14	.23	3.22	-2.78	.26	.28	-.27

TABLE I. We set $G_3 = 0.83$ and compare results for g_3^* with and without σ_3 in the different approximations.



arXiv:1709.03696