Matter matters in Asymptotically Safe gravity

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based on
arXiv: 1311.2898 [hep-th]
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Motivation

Matter in Quantum Gravity

- usually ignored or not dynamical
- the addition of matter d.o.f. could alter the character of the theory

  e.g. Yang-Mills theory with too many fermions

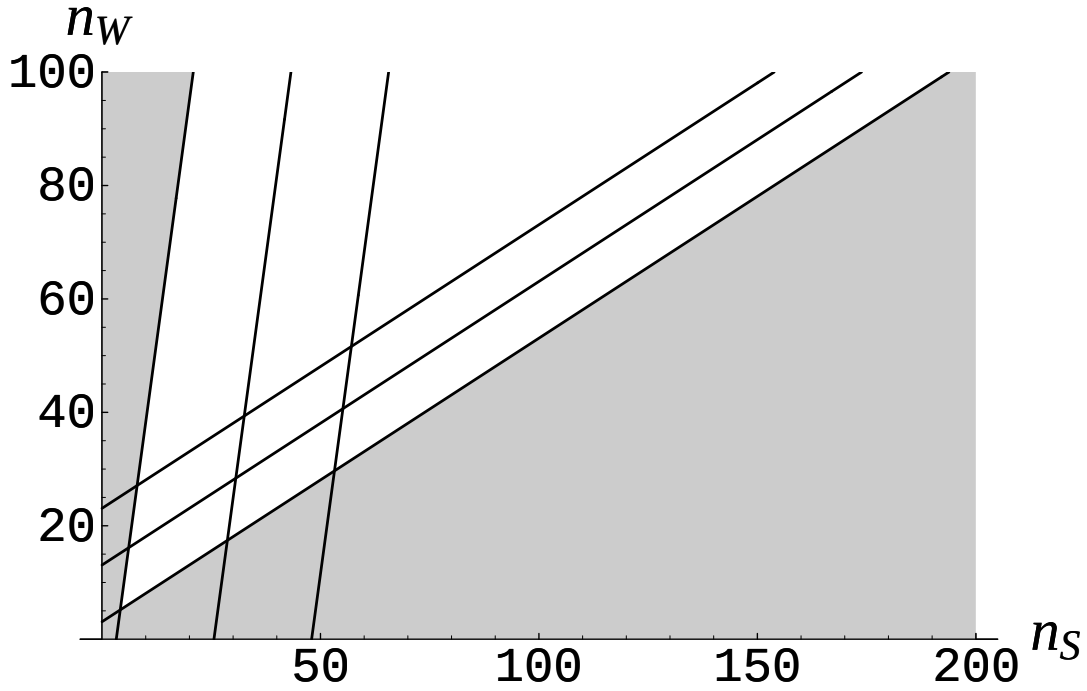
Matter in the AS scenario

- Straightforward inclusion of matter

  early work by Percacci and Perini (improvement)
- Quantum gravity fluctuation generate matter interaction

  Eichhorn and Gies, Vacca and Zanusso
- Is SM compatible with a gravitational FP?

Review of prevous work by Percacci and Perini[1]



- RG flow closure

  $\eta_h \equiv \eta_G$

  $\eta_c = \eta_{\text{matter}} = 0$
- "Type I" regulator

  wrong for fermions[2]
- No max number of fermions or scalars

[1] R. Percacci and D. Perini, Phys. Rev. D **67**, 081503 (2003), R. Percacci and D. Perini, Phys. Rev. D **68**, 044018 (2003).

[2] P. D. and R. Percacci, Phys. Rev. D **87**, no. 4, 045002 (2013)

Why matter matters in AS?

Our truncation is given by

$$\Gamma_k = \Gamma_{\rm EH} + S_{\rm gf} + S_{\rm gh} + \Gamma_{\rm matter}$$

- Einstein-Hilbert Action with the standard gauge fixing and ghosts
- Massless minimally coupled matter and gauge fields (N_S, N_D, N_V)

  fermions $\longrightarrow$ *tetrads formulation. Symmetric gauge fixing. No* $O(4)$ *ghosts*

  gauge fields $\longrightarrow$ *Abelian. No mixing between gauge and diffeo ghosts.*
- For a consistent closure of the βfunctions graviton and matter anomalous dimensions are needed[3]

[3] pure gravity by Codello,D'Odorico and Pagani, arXiv:1304.4777 [gr-qc]

The method

Computation of anomalous dimensions

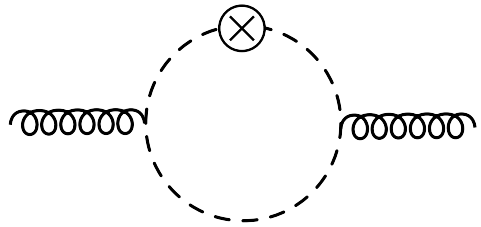
$$\eta_\Phi = -\partial_t \ln Z_\Phi \qquad \Phi = (h, c, S, D, V)$$

- Look at the two point functional
- Flat background
- Diagrammatic and momentum space techniques

Combined with the usual computation for $\partial_t \tilde{G}$ and $\partial_t \tilde{\Lambda}$

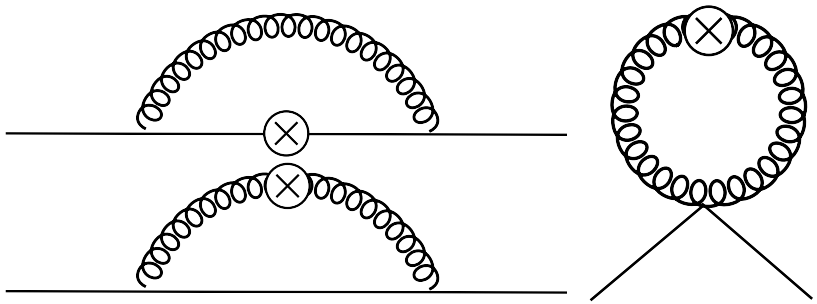
- Spherical background
- Keeping into account all the anomalous dimensions
- Type II cutoff for the matter fields and a Type I cutoff for the graviton and ghosts

The relevant contribution to the graviton wave function renormalization



- tadpole diagrams contributions vanishes
- ignoring gauge ghost contributions

We computed also the running of matter wave function renormalization



One loop analysis

- Neglect anomalous dimensions
- Expand beta functions to first orders in $\tilde{\Lambda}$

$$\begin{aligned}
\beta_{\tilde{G}} &= 2\tilde{G} + \frac{\tilde{G}^2}{6\pi}\left(N_S + 2N_D - 4N_V - 22\right), \\
\beta_{\tilde{\Lambda}} &= -2\tilde{\Lambda} + \frac{\tilde{G}}{4\pi}\left(N_S - 4N_D + 2N_V + 2\right) \\
&\quad + \frac{\tilde{G}\tilde{\Lambda}}{6\pi}\left(N_S + 2N_D - 4N_V + 8\right).
\end{aligned}$$

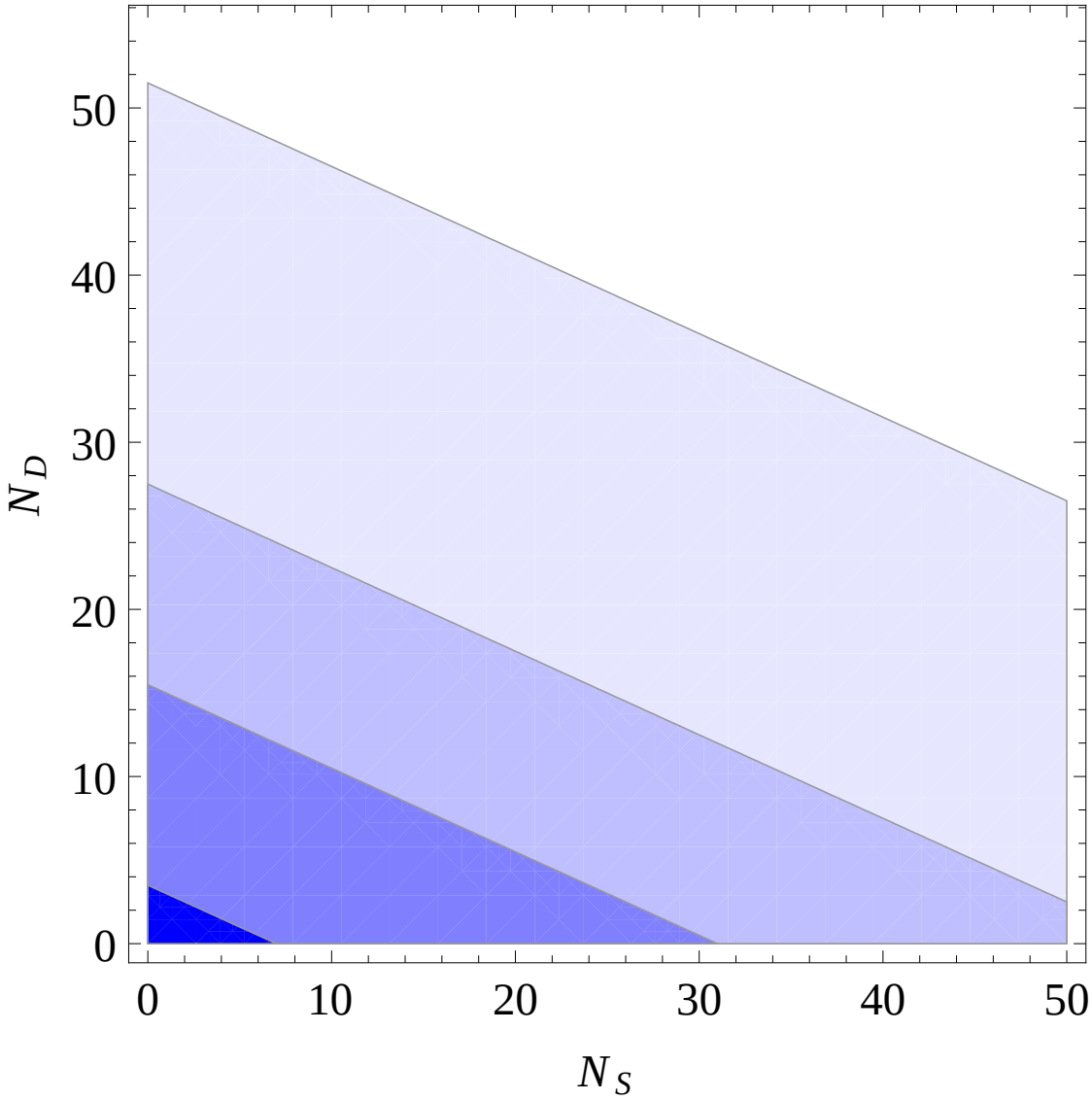
- red numbers encodes the effect of gravitons and ghosts
- we can study the problem analytically (for simplicity $d = 4$)
- what is the effect of matter in this approximation?

There is a non trivial Fixed point

$$\begin{aligned} \tilde{\Lambda}_* &= -\frac{3}{4}\frac{N_S - 4N_D + 2N_V + 2}{N_S + 2N_D - 4N_V - 7}\,, \\ \tilde{G}_* &= -\frac{12\pi}{N_S + 2N_D - 4N_V - 22}\,. \end{aligned}$$

- We required the positivity of $\tilde{G}_*$

  $N_S + 2N_D - 4N_V - 22 < 0$
- There are divergences. We consider the region of Fixed points connected with the "no matter" one.
- The critical exponents are both positive in the allowed region
- 2 combination of 3 parameters.


50
40
30
20
10
0
N_D
0
10
20
30
40
50
N_S

Results for the full system

Selection criteria (continuous deformation of the fixed point without matter)

- we require $\tilde{G}_* > 0$
- discard fixed points with less than two relevant directions
- rule out too large critical exponents (≈ 20 - optional)

We find severe restrictions on the number of matter fields compatible with AS gravity.

Anomalous dimensions and predictivity (critical exponents at the FP and anomalous dimension)

$$\mathcal{O} = \Phi^n \longrightarrow g_{\mathcal{O}} = \bar{g}_{\mathcal{O}} \frac{k^{-d+nd_\Phi}}{Z_\Phi^{\frac{n}{2}}}$$

the relative critical exponent

$$\theta_{\mathcal{O}} = -\frac{\partial \beta_{g_{\mathcal{O}}}}{\partial g_{\mathcal{O}}}|_{g_{\mathcal{O}}=g_{\mathcal{O}*}} = -\left(-d + nd_\Phi + \frac{n}{2}\eta_\Phi\right) + \dots \ .$$

Requiring just a finite number of operator will be shifted to relevance

$$\eta_\Phi > -2d_\Phi + \frac{2d}{n} \xrightarrow{n\to\infty} -2d_\Phi$$

For the graviton $\eta_h > -d + 2$ is an additional requirement on the fixed point!

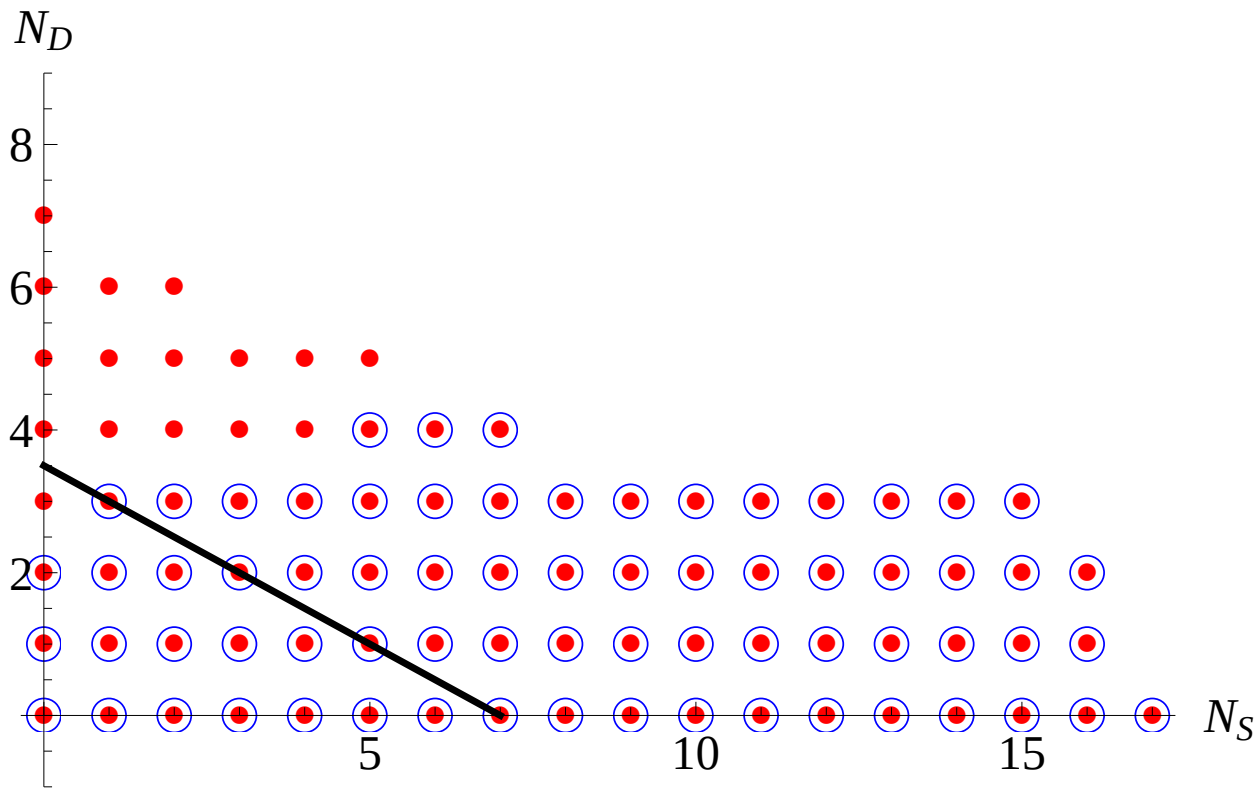
Effects of matter

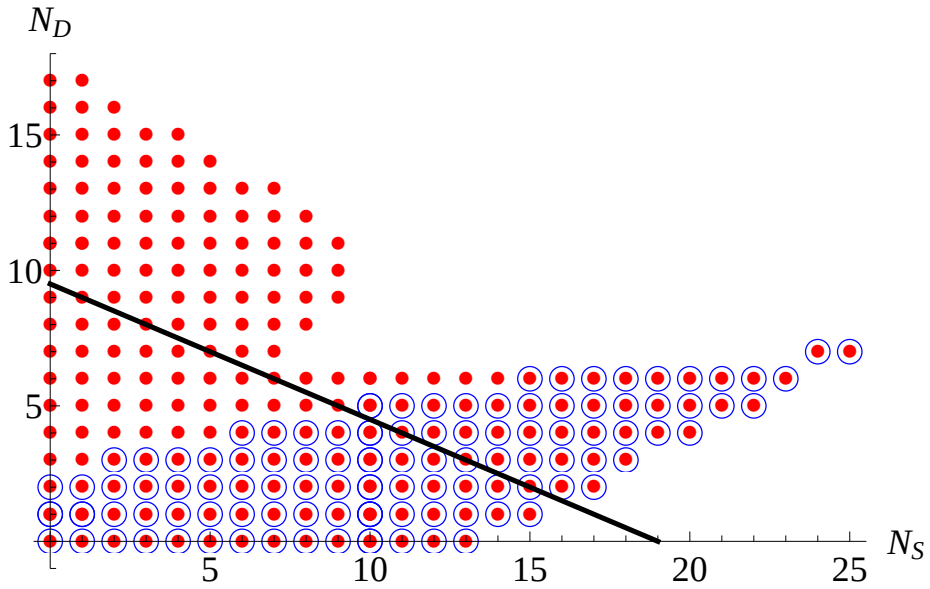
- Scalar fields $\rightarrow \tilde{G}_*$ to smaller values and $\tilde{\Lambda}_*$ to larger positive values

  critical number of scalar fields, strong increase on the critical exponents
- Fermion fields $\rightarrow \tilde{G}_*$ to larger values and $\tilde{\Lambda}_*$ to more negative values

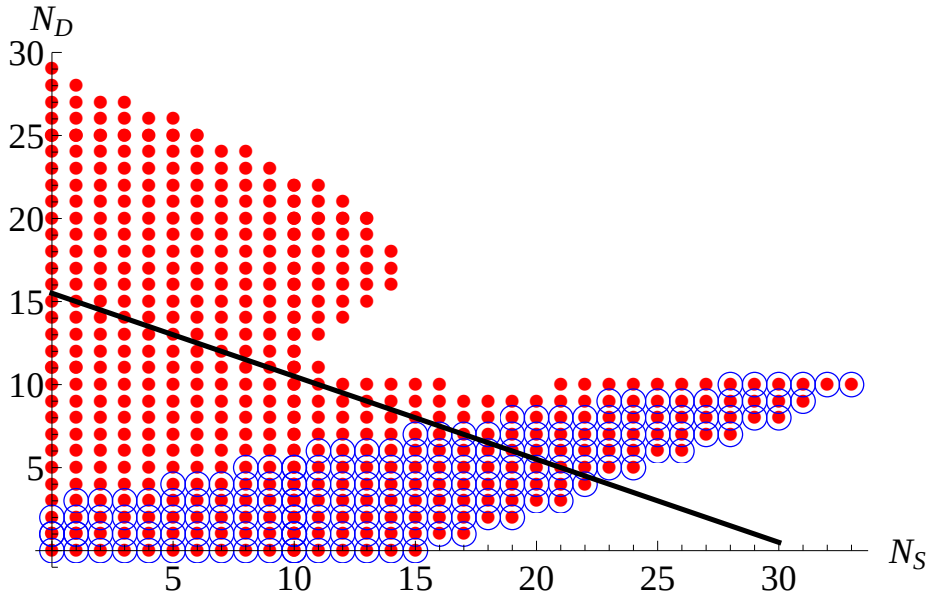
  critical number of fermion fields, small effect on the critical exponents
- Vector fields $\rightarrow \tilde{G}_*$ to smaller values and $\tilde{\Lambda}_*$ to larger positive values

  no maximal number of vector fields but predictivity might not be preserved





Region with 6 gauge fields



Region with 12 gauge fields

Specific matter models

Disclaimer:

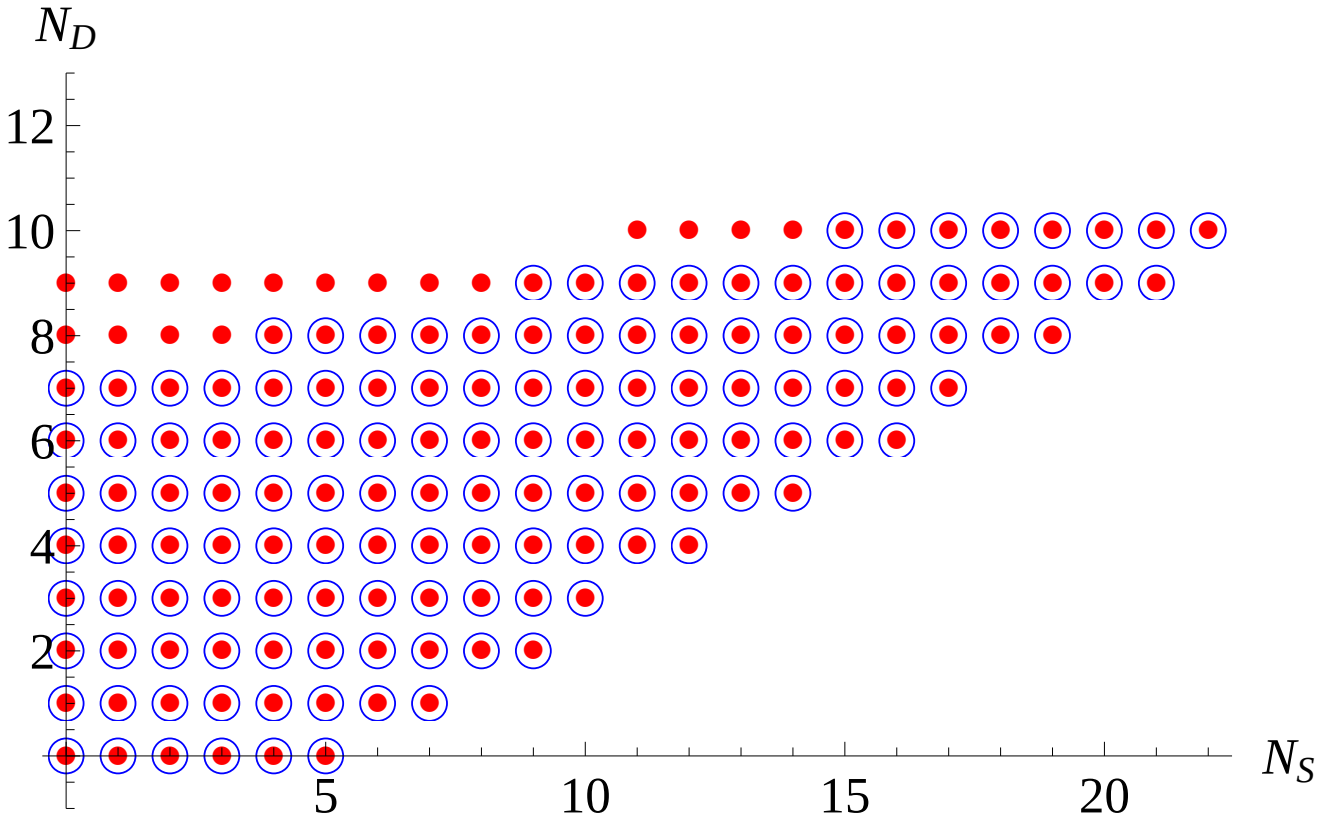
1. particular truncation
2. neglecting matter self interaction
3. all the gauge fields are abelian

Model	N_S	N_D	N_V	$\tilde{G}_*$	$\tilde{\Lambda}_*$	θ_1	θ_2	η_h
no matter	0	0	0	1.45	-0.008	3.08	1.55	0.07
SM	4	45/2	12	5.34	-7.03	3.90	1.95	-34.90
SM +dm scalar	5	45/2	12	6.32	-8.19	3.90	1.95	-40.87
SM+ 3 ν's	4	24	12	8.26	-11.90	3.90	1.98	-53.33
SM+3ν's + axion+dm	6	24	12	15.38	-21.57	3.90	1.99	-97.33
MSSM	49	61/2	12	-	-	-	-	-
SU(5) GUT	124	24	24	-	-	-	-	-
SO(10) GUT	97	24	45	-	-	-	-	-

- SM and extension are compatible with a Gravitational FP
- large η_h means predictivity needs to be examined carefully

Higher dimensions

- Extra dimensions are not required in AS scenario of pure gravity but compatible
- For $d = 5, 6$ the Standard Model matter degrees of freedom are incompatible with a viable gravitational fixed point



F.P. in $d = 5$ and 12 gauge fields.

Dynamical Quantum Gravity scale

- In QCD quantum fluctuations lead to the dynamical generation of $\Lambda_{\rm QCD}$
- A quantum-gravity scale will emerge dynamically

  - *transition scale to the fixed-point regime*

  - *the dimensionful Newton coupling pass from constant to a scale-free regime in which* $G(k^2) \sim \frac{1}{k^2}$

  - *close to the Planck scale in previous studies of the Einstein-Hilbert truncation*[4]
- Matter fluctuations change the scale:

  - *scalars seem to have little effect on the transition scale*

  - *fermions shift this scale towards larger values*

[4] M. Reuter and H. Weyer, JCAP **0412**, 001 (2004)

Conclusions

- Compatibility of matter degrees of freedom with the asymptotic safety scenario for gravity

  - effect of scalar, fermionic and abelian gauge field fluctuations on the existence of an interacting fixed point

  - correct cutoff type on fermion fields

  - fluctuations field anomalous dimensions

  - predictability and the contraint on the anomalous dimension

  - upper limits on the allowed number of scalar, fermionic and vector degrees of freedom

- Focusing on particular models
  - *standard Model matter content is compatible with the existence of a NGFP*
  - *observationally motivated extensions are compatible too*
  - *the other models are not*
- Going to larger dimensions
  - *the allowed region shrinks*
  - *no more compatibility with the SM*
- Effect of matter degrees of freedom on the quantum gravity scale

Thank you!