Pietro Dona'

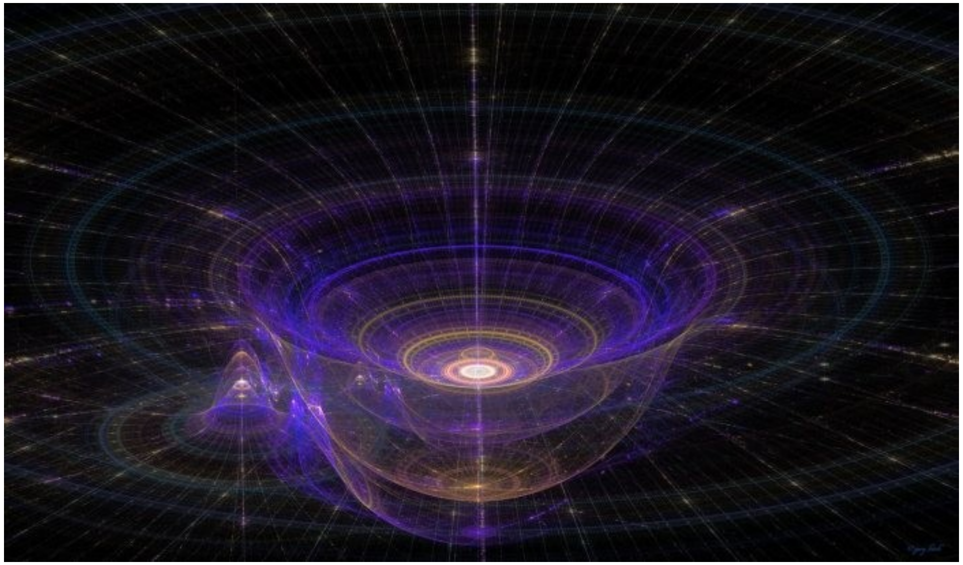
Fudan University

Asymptotic safety in an interacting system of gravity and matter

14 - 12 - 2015

2nd LeCosPA International Symposium "Everything about Gravity"

How to test Quantum Gravity?

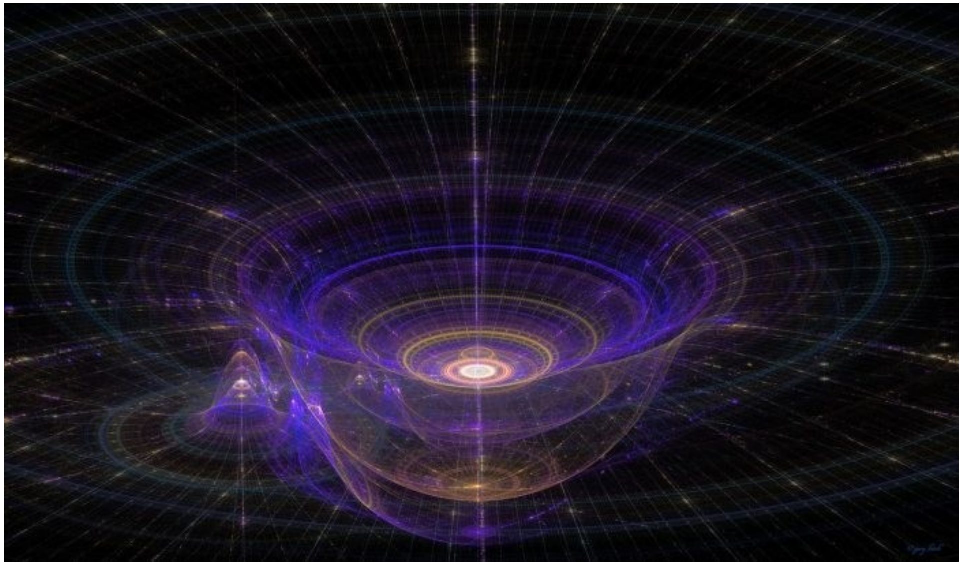


Direct tests?

Very challenging!

High precision data from particle physics experiments

How to test Quantum Gravity?



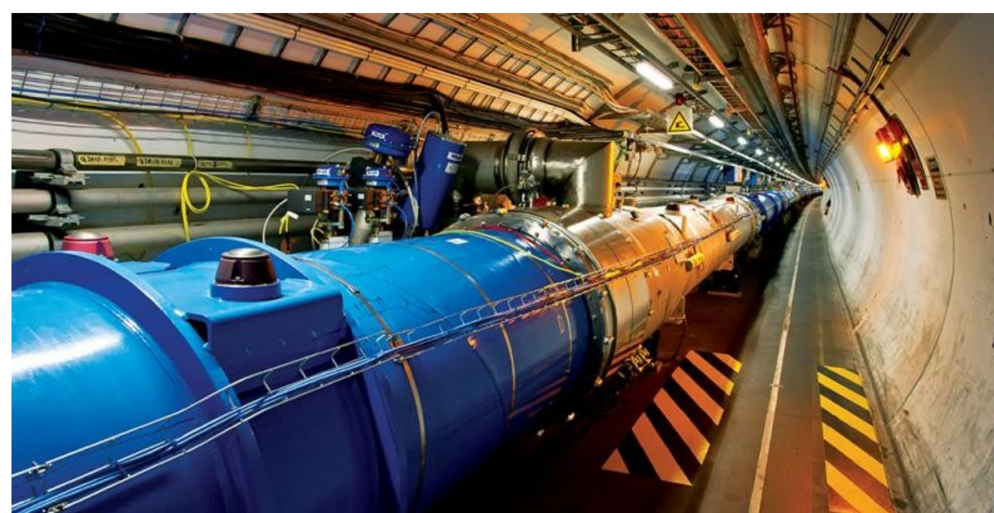
Direct tests?

Very challenging!

High precision data from particle physics experiments

Quantum gravity compatibility with matter fields (Standard Model or extensions)

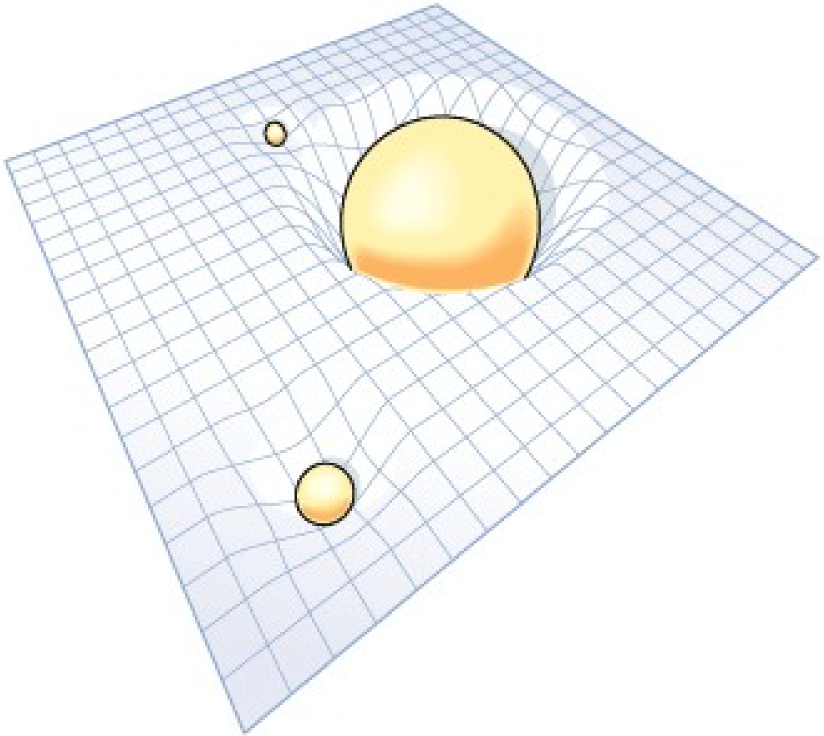
Possibility to test Quantum Gravity, NOW!



Asymptotic Safety: QFT of Spacetime

Curvature = Matter

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G_N T_{\mu\nu}$$



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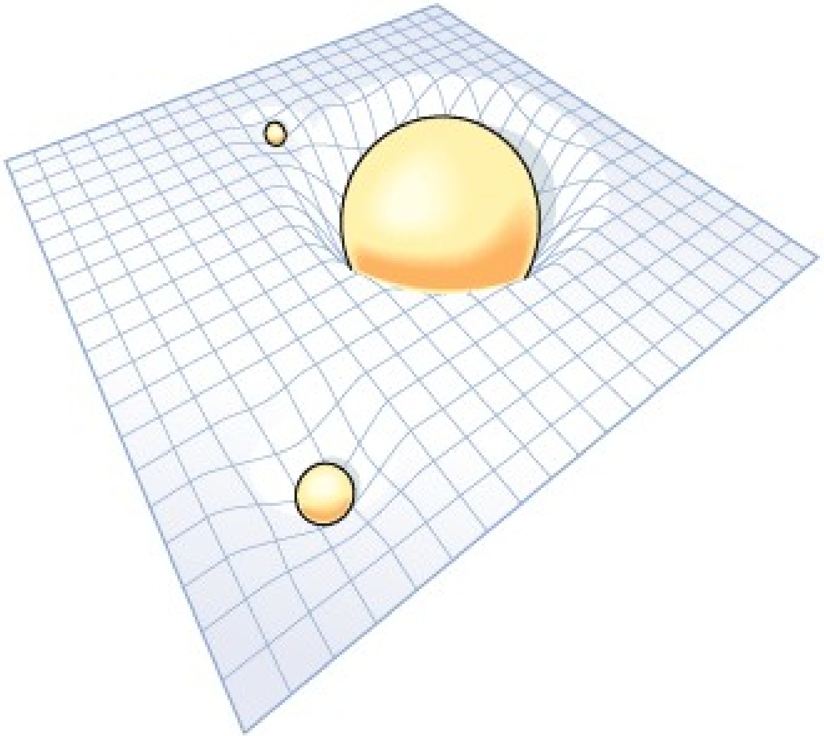
Matter → Quantum Field

$$\langle \mathcal{O}(\phi) \rangle = \int \mathcal{D}\phi \, \mathcal{O}(\phi) \exp iS(\phi)$$



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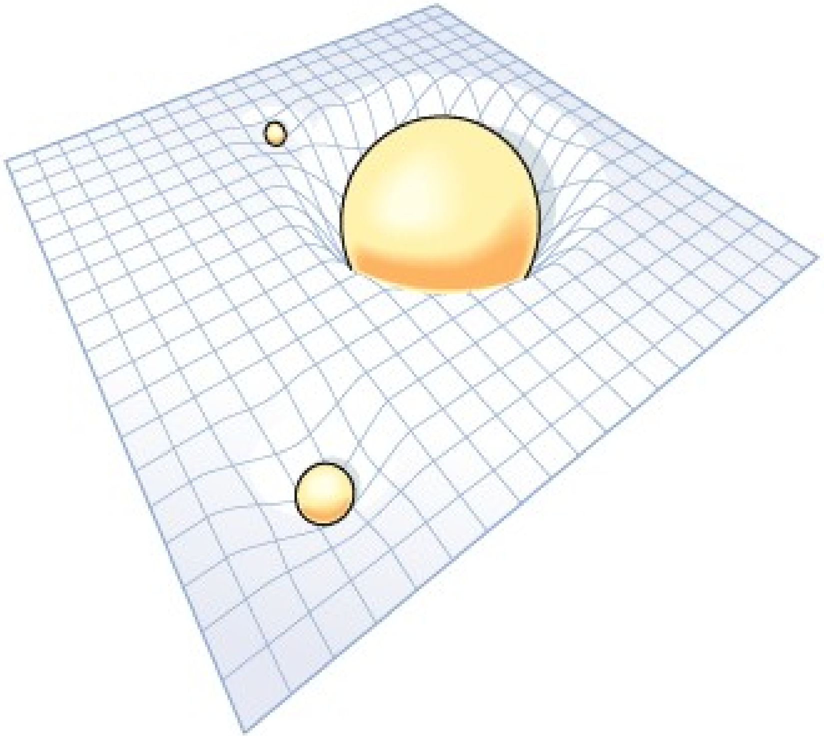


Quantum gravity scenario in the framework of a QFT.

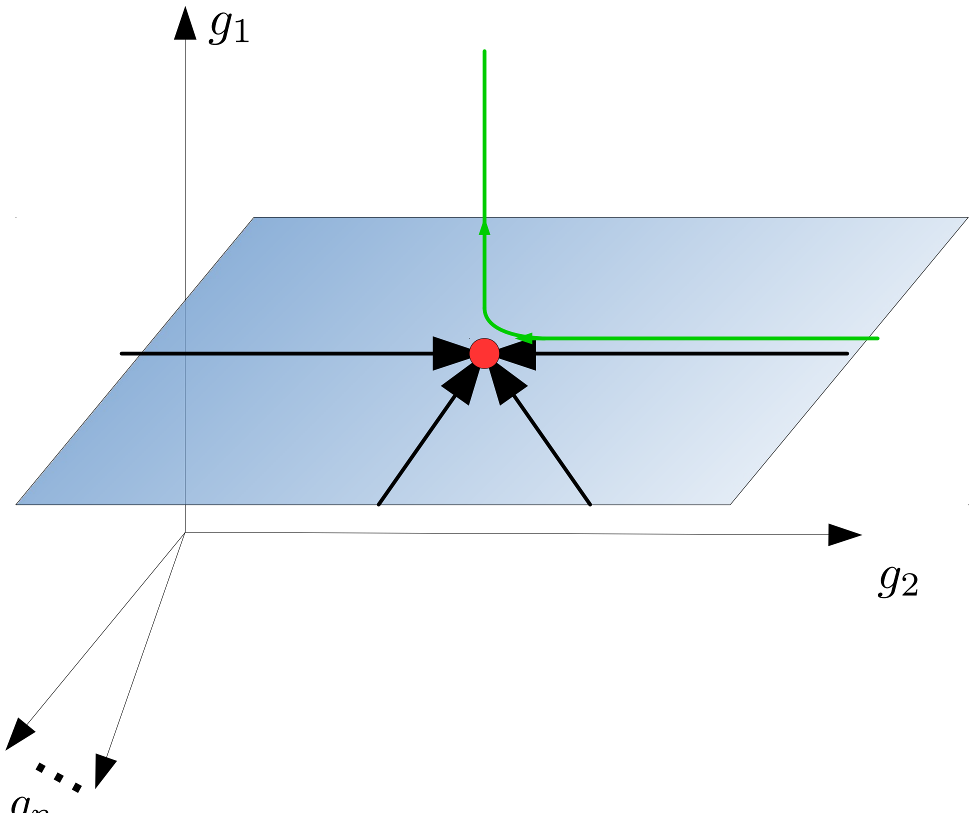
[S. Weinberg, '79]

Goal: $\int_{spacetime} \mathcal{D}g_{\mu\nu} \exp -S(g_{\mu\nu})$

Asymptotic Safety: QFT of Spacetime

Existence of a UV-stable trajectory of an interacting fixed point of the renormalization group

The space of such trajectories is finite dimensional



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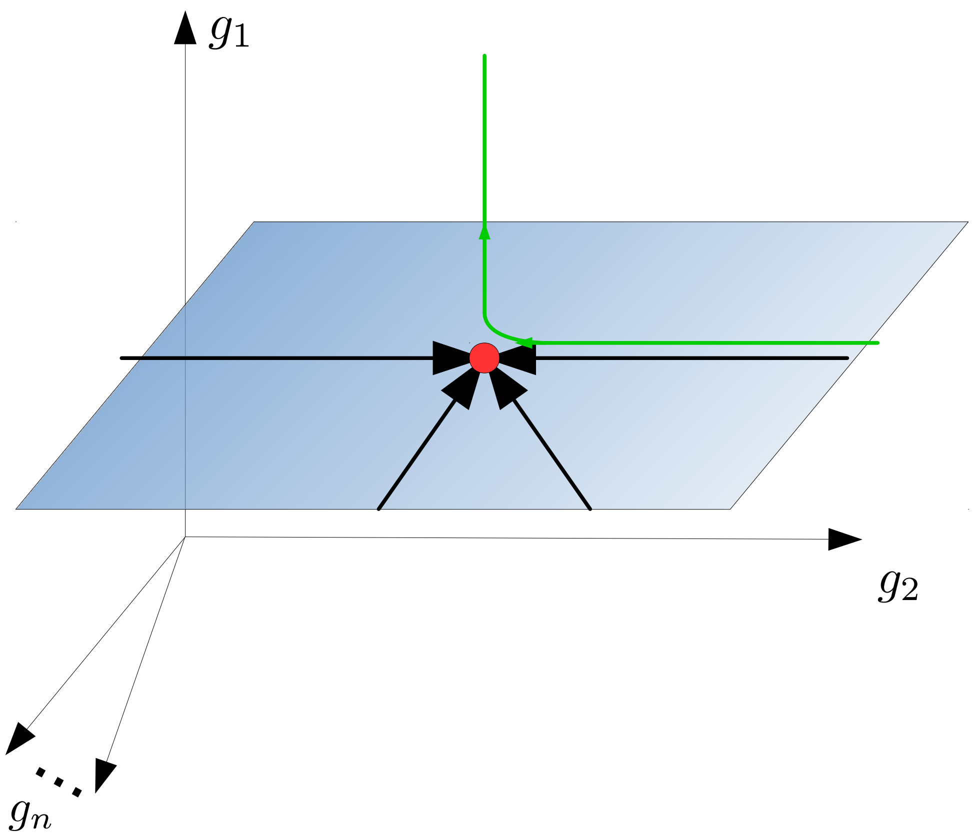


Beta functions

$$k\partial_k g_n = \beta_{g_n}(g_1, \ldots g_n)$$

Non-perturbative computations

Functional Renormalization Group (FRG)

Asymptotic Safety: Some Evidences

$$\frac{1}{16\pi G_k}\int d^dx\sqrt{g}\,(-R+2\Lambda_k)+\Gamma_{\text{gauge}-\text{fixing}}$$
$$+\Gamma_{\text{ghost}}+\int\sqrt{g}\,\left(f(R)+R_{\mu\nu}R^{\mu\nu}+\ldots\right)$$

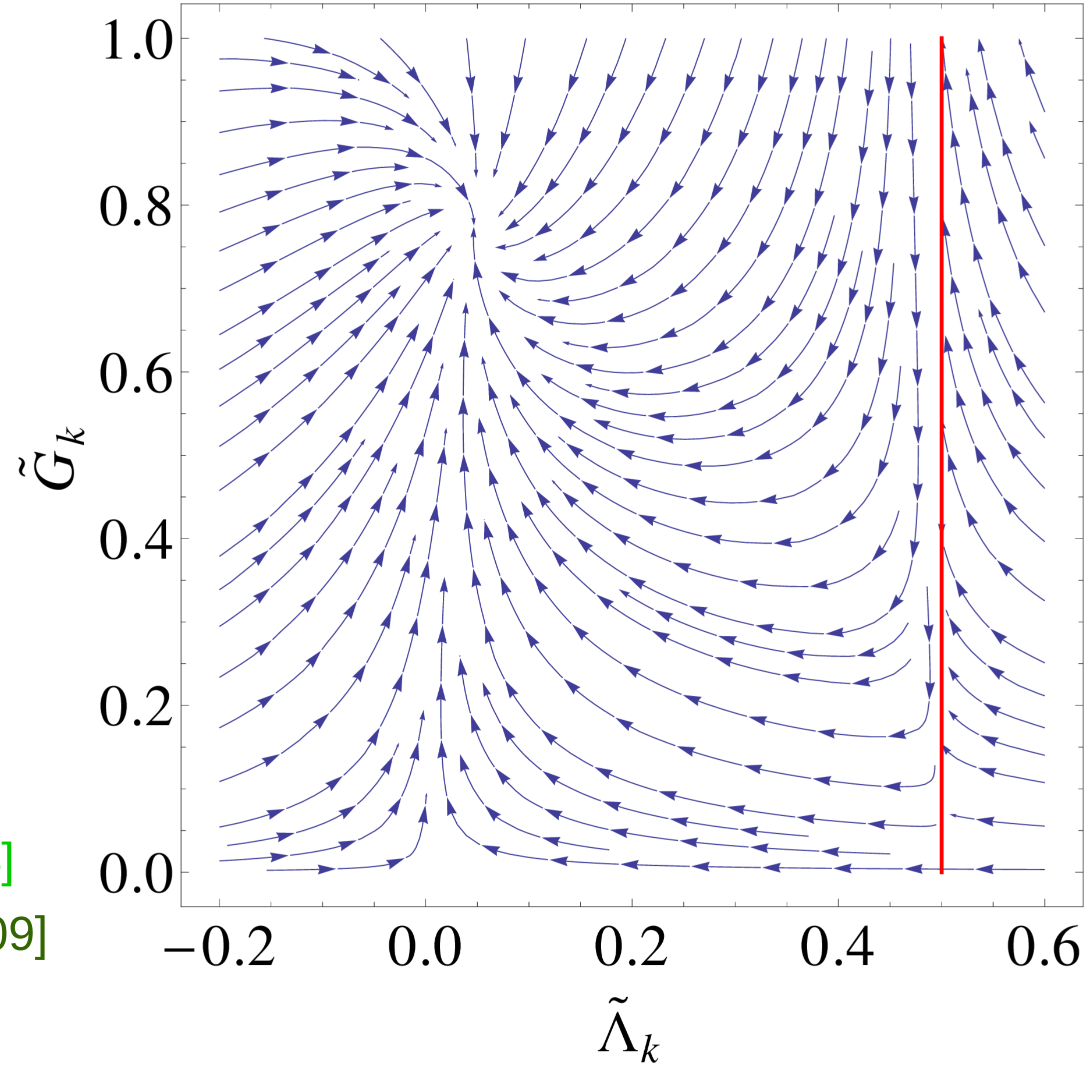
[M. Reuter, 1996; M. Reuter, F.Saueressig, 2001; D. Litim, 2004]

[E. Manrique, M. Reuter, F. Saueressig 2009, 2010; I. Donkin, J. Pawlowski 2012; A. Codello, G. D'Odorico, C. Pagani 2013]

[A.Eichhorn, H.Gies, M.Scherer (2009), A.Eichhorn, H. Gies 2010; A.Eichhorn 2013]

[A. Codello, R. Percacci, C. Rahmede 2008; D.Benedetti, F. Caravelli 2012; K. Falls, D. Litim, K. Nikolakopoulos 2013; J. Dietz, T. Morris 2013; M. Demmel, F. Saueressig, O. Zanusso 2014]

[D. Benedetti, P. Machado, F. Saueressig 2009]



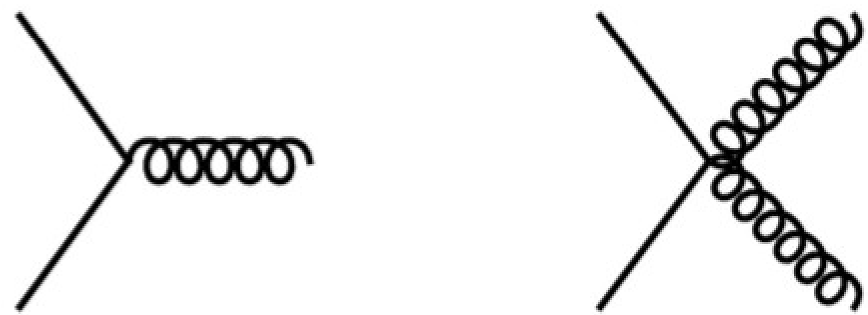
What matters?

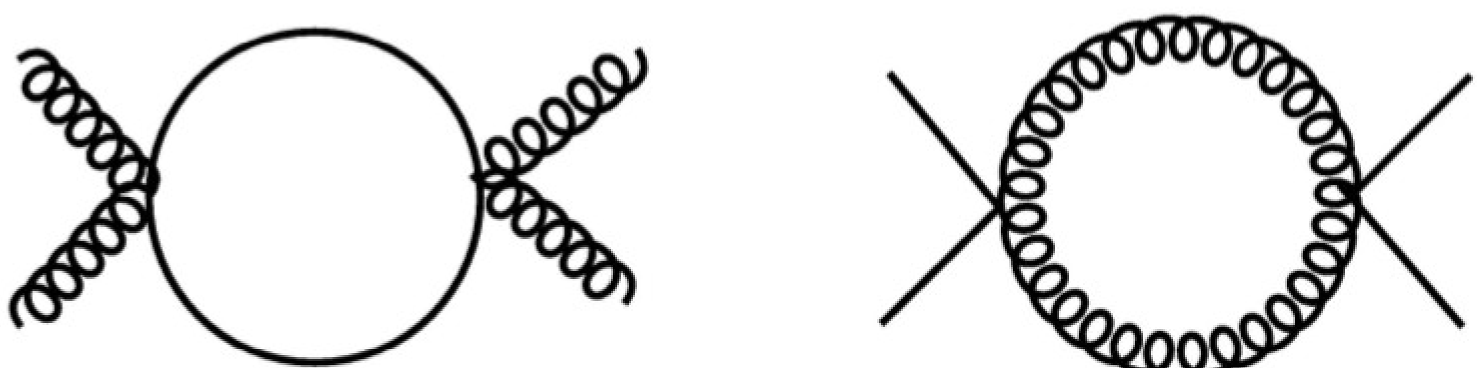
The Universe contains interacting Matter and Gravity

Fundamental matter degrees of freedom

Emergent matter

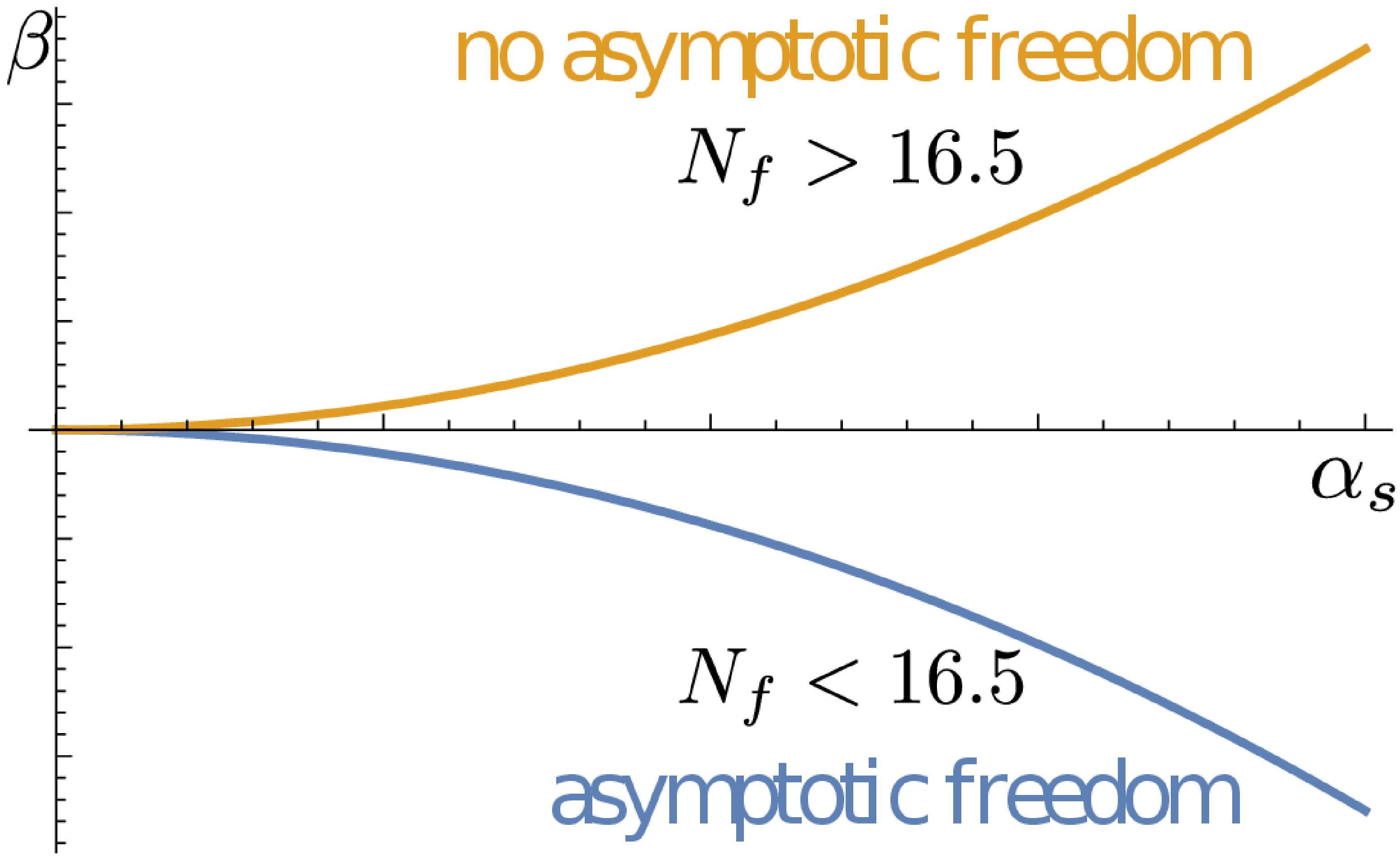
$$\int \mathrm{d}^d x \; g^{\mu\nu} \partial_\mu \phi \, \partial_\nu \phi \longrightarrow$$





Learning by example: possible effects of matter

QCD is the perfect example! Asymptotic freedom:



Matter effects on the gravitational fixed point

Einstein-Hilbert with explicit computation of anomalous dimensions $\eta_h = -k\partial_k \log Z_h$

$$\frac{1}{16\pi G_k}\int \mathrm{d}^d x\,\sqrt{\bar{g}}\,\left(\bar{R} - 2\Lambda_k\right) + \frac{Z_h}{2}\int \mathrm{d}^d x\,\sqrt{\bar{g}} h_{\mu\nu} M^{\mu\nu\rho\sigma}\left(-\bar{D}^2\right) h_{\rho\sigma}$$

Matter effects on the gravitational fixed point

[P.D., A. Eichhorn, and R. Percacci 2013, 2014]

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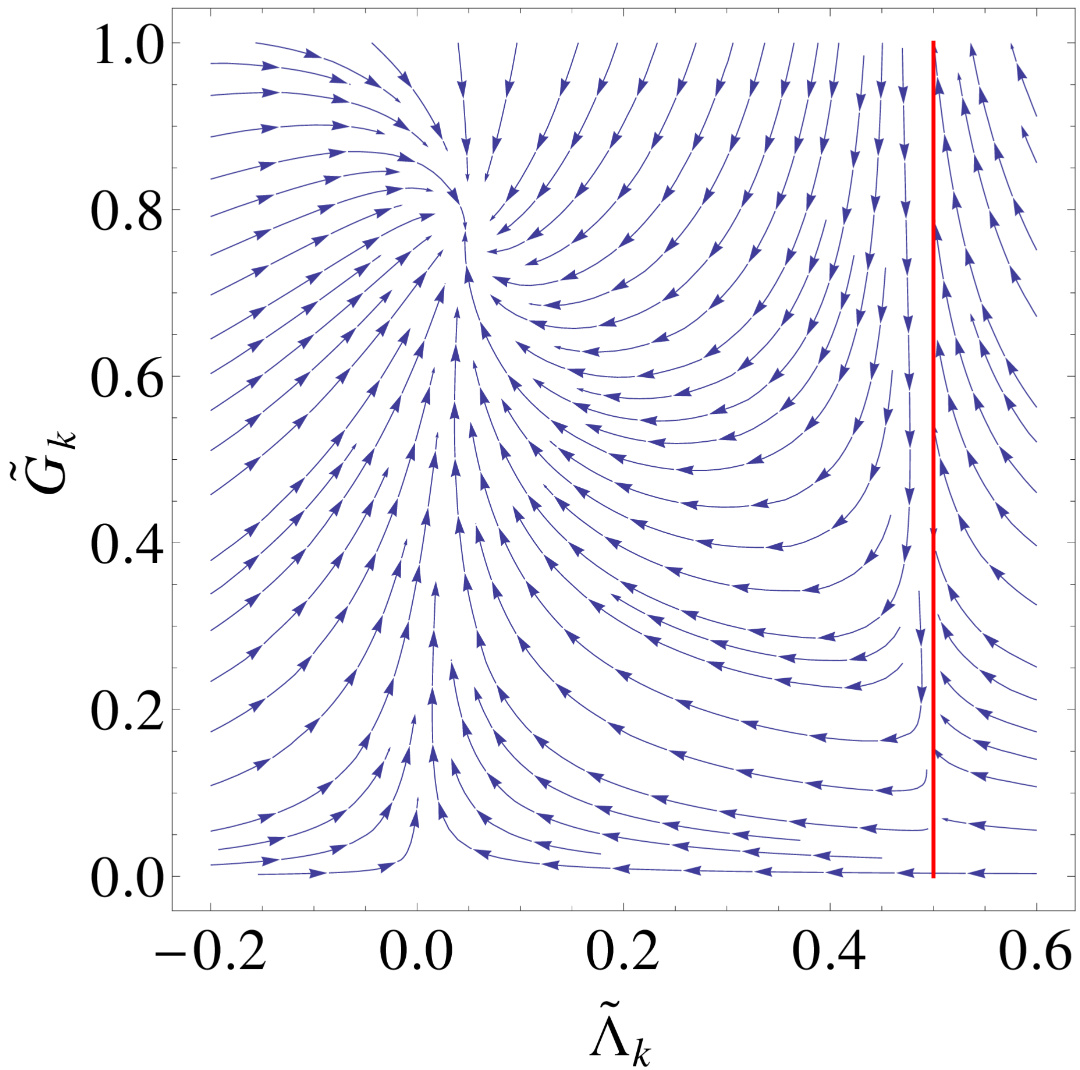
Minimally coupled massless matter

N_S Scalars: $\frac{Z_S}{2}\int \mathrm{d}^d x\sqrt{g}\, g^{\mu\nu}\partial_\mu\phi^i\partial_\nu\phi_i \quad i=1,\ldots,N_S$

N_D Fermions: $iZ_D\int \mathrm{d}^d x\sqrt{g}\,\bar{\psi}_i \not{\nabla}\psi^i \quad i=1,\ldots,N_D$

N_V U(1) fields: $\frac{Z_V}{4}\int \mathrm{d}^d x\sqrt{g}\, g^{\mu\nu} g^{\rho\sigma} F^i_{\mu\rho} F^i_{\nu\sigma} + \text{Gauge Fixing}$
$i=1,\ldots,N_V$

Matter effects on the gravitational fixed point



$N_S,\ N_D,\ N_V$

?

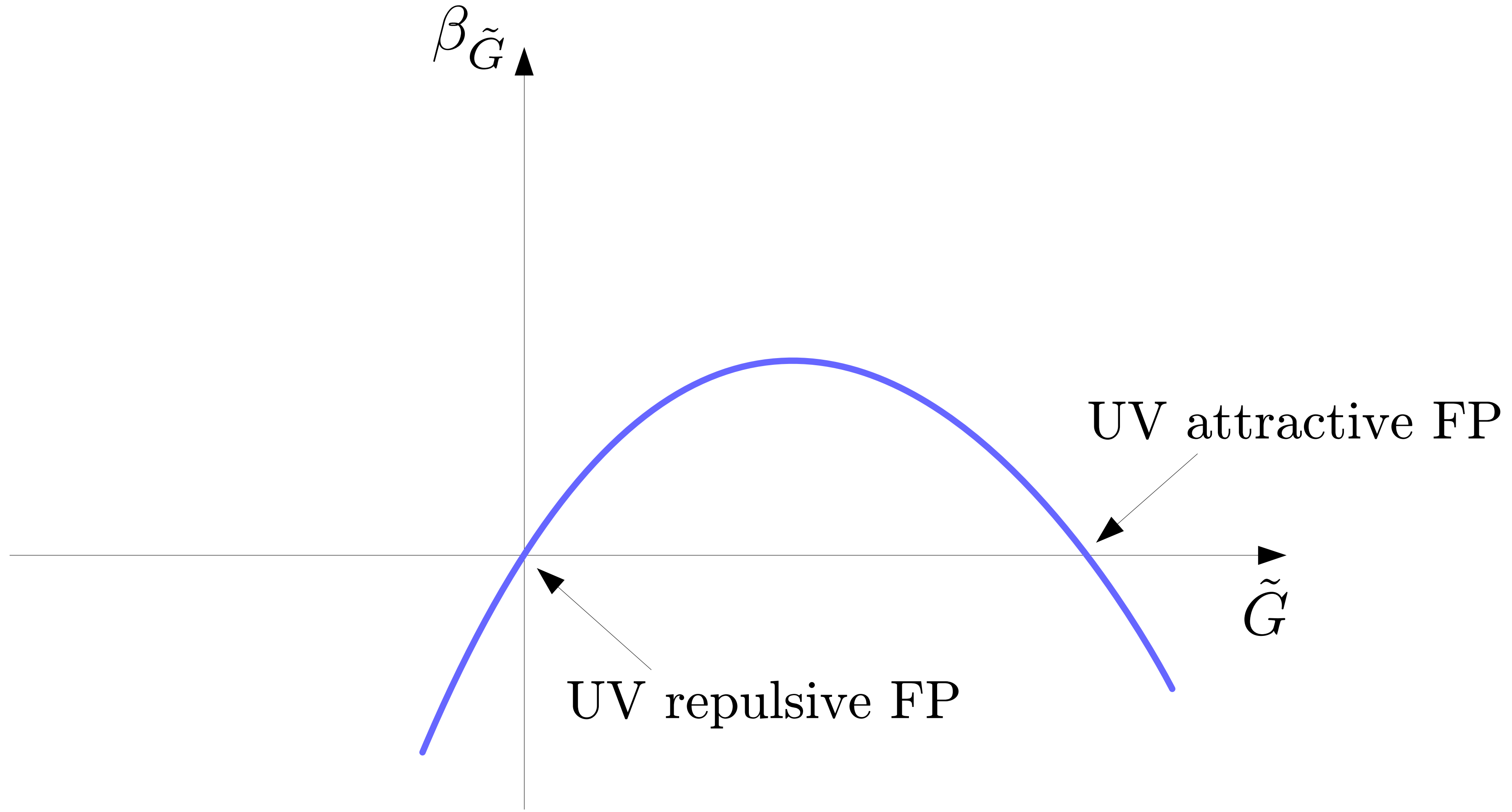
$\beta_G,\ \beta_\Lambda$

$\eta_h,\ \eta_c,\ \eta_S,\ \eta_D,\ \eta_V$

"Perturbative" analysis

(vanishing anomalous dimensions)

$$\beta_{\tilde{G}} = 2\tilde{G} + \frac{\tilde{G}^2}{6\pi}\,(\qquad\qquad\qquad - 46)$$



"Perturbative" analysis

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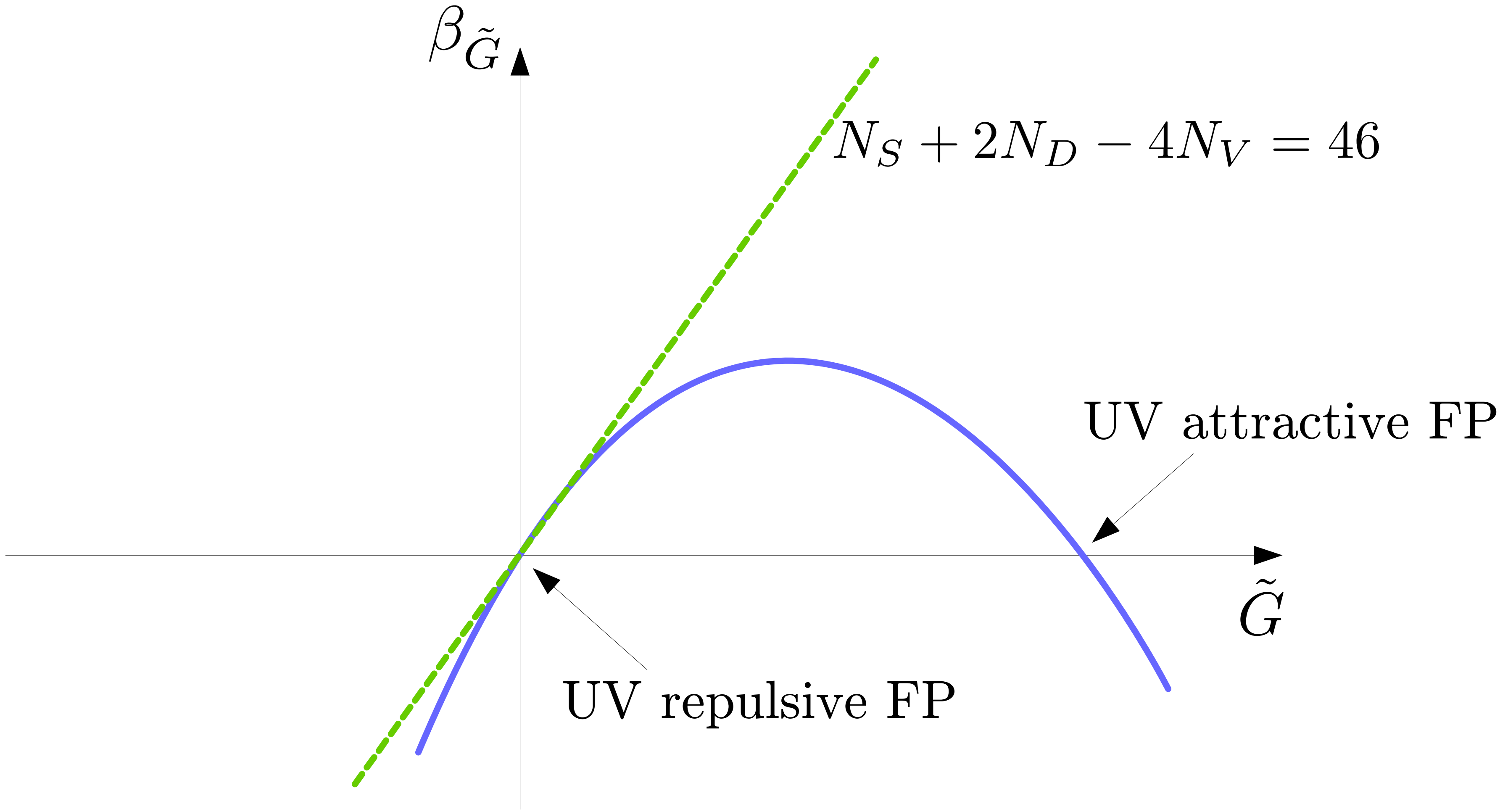
$$\beta_{\tilde{G}} = 2\tilde{G} + \frac{\tilde{G}^2}{6\pi}\left(N_S + 2N_D - 4N_V - 46\right)$$



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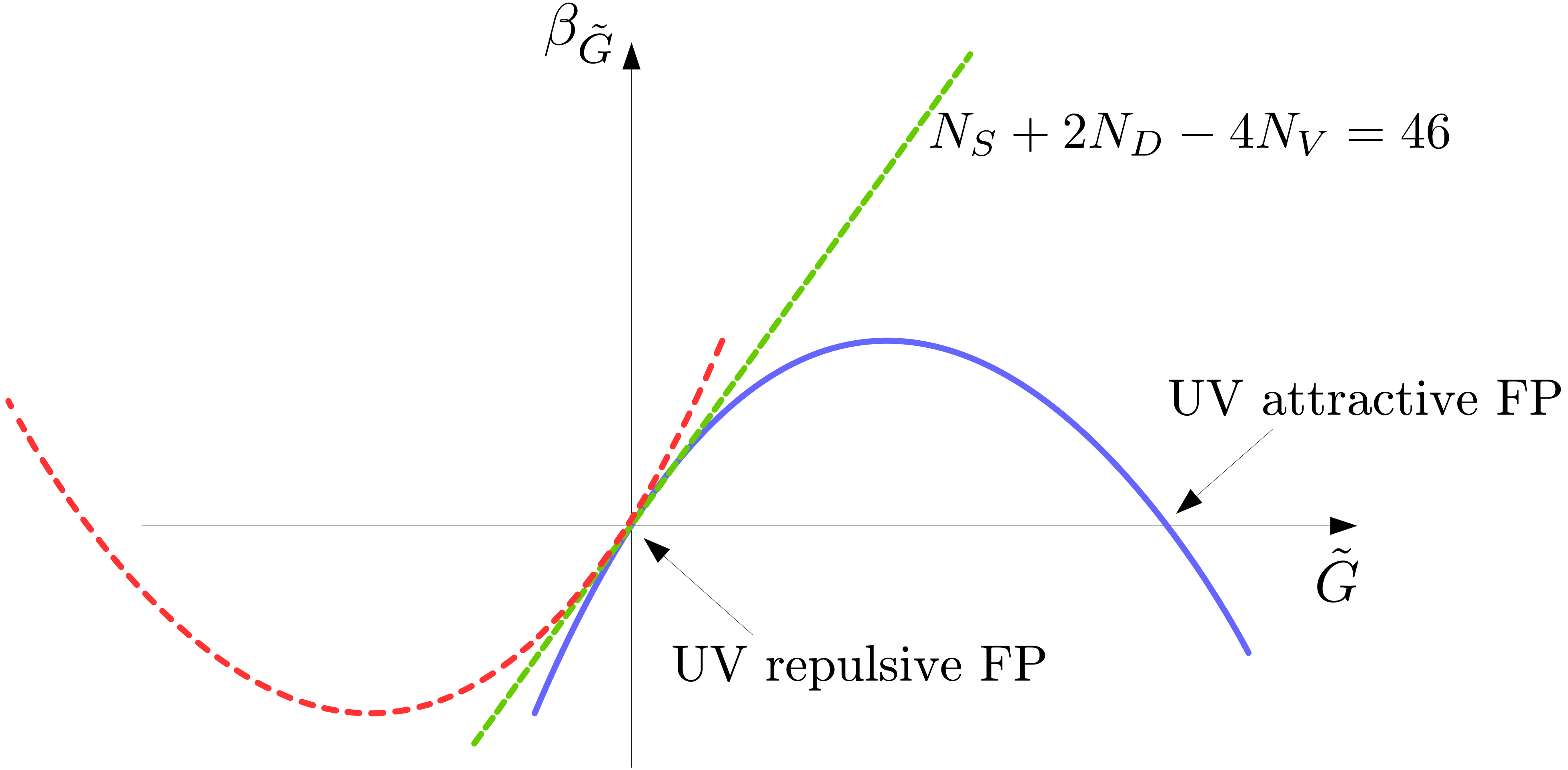
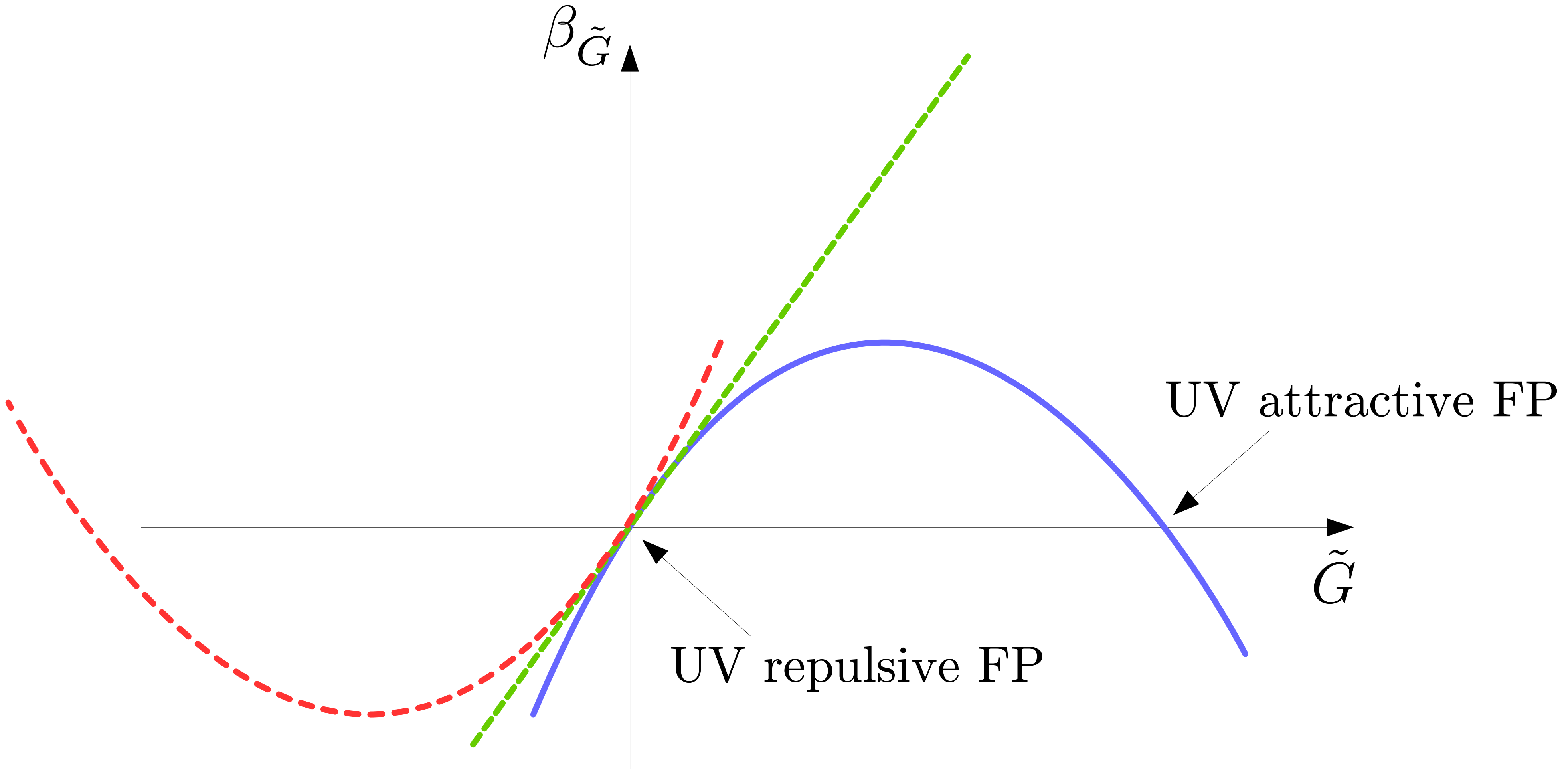


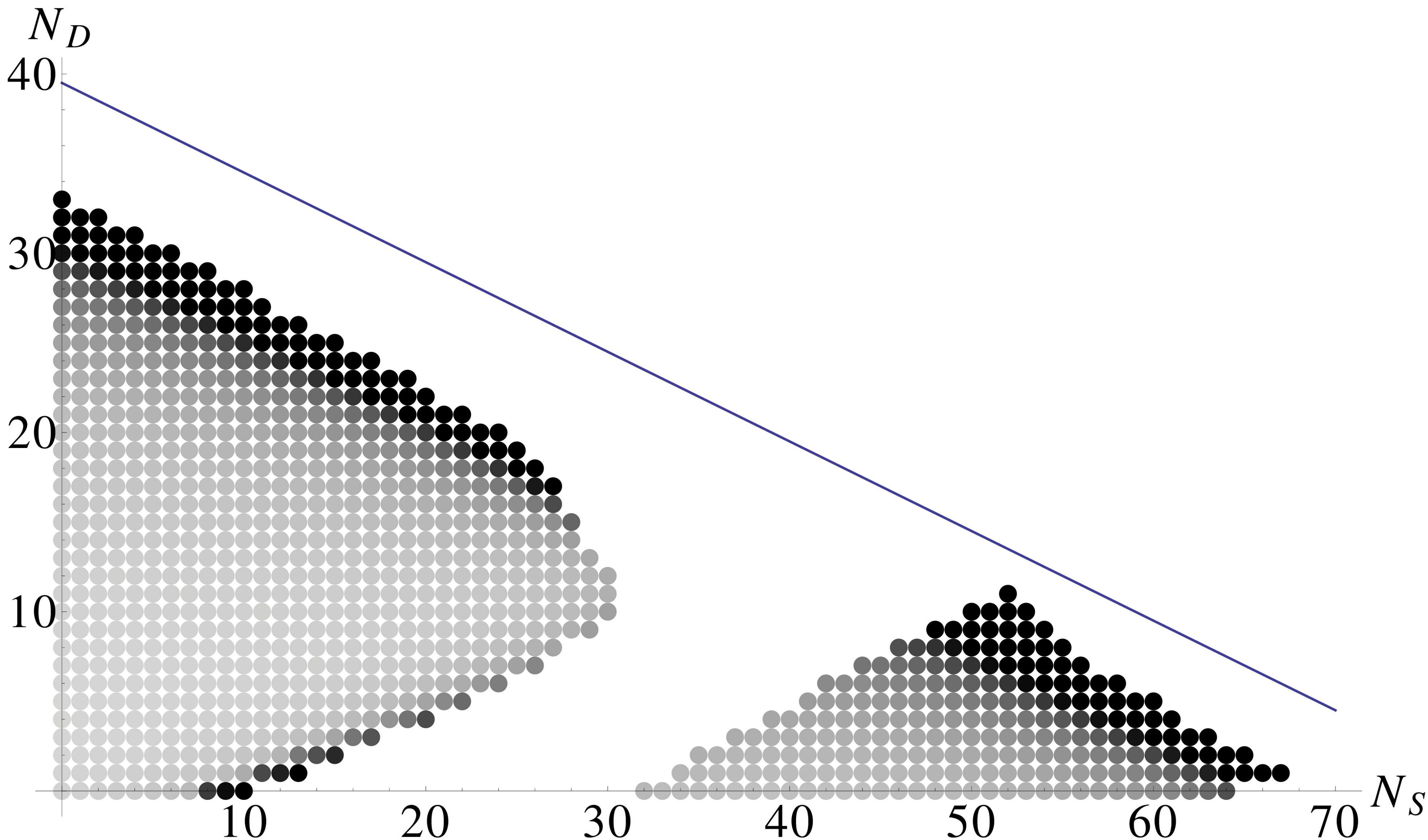
"Perturbative" analysis

(vanishing anomalous dimensions)

For a given number of vectors N_V, there is an upper limit on the number of scalars N_S and fermions N_D



$(N_V = 12)$ Full results and Matter Models



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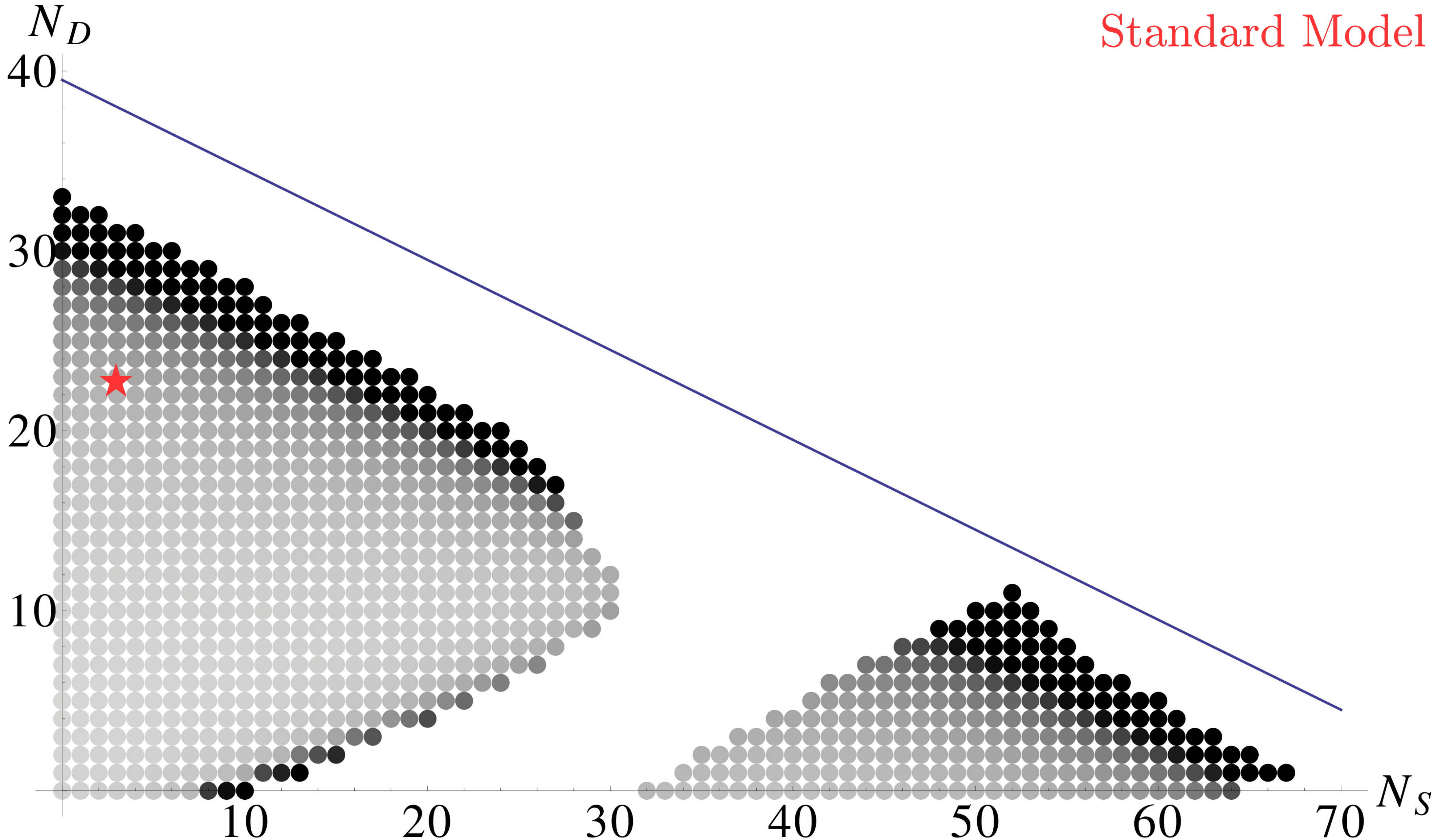

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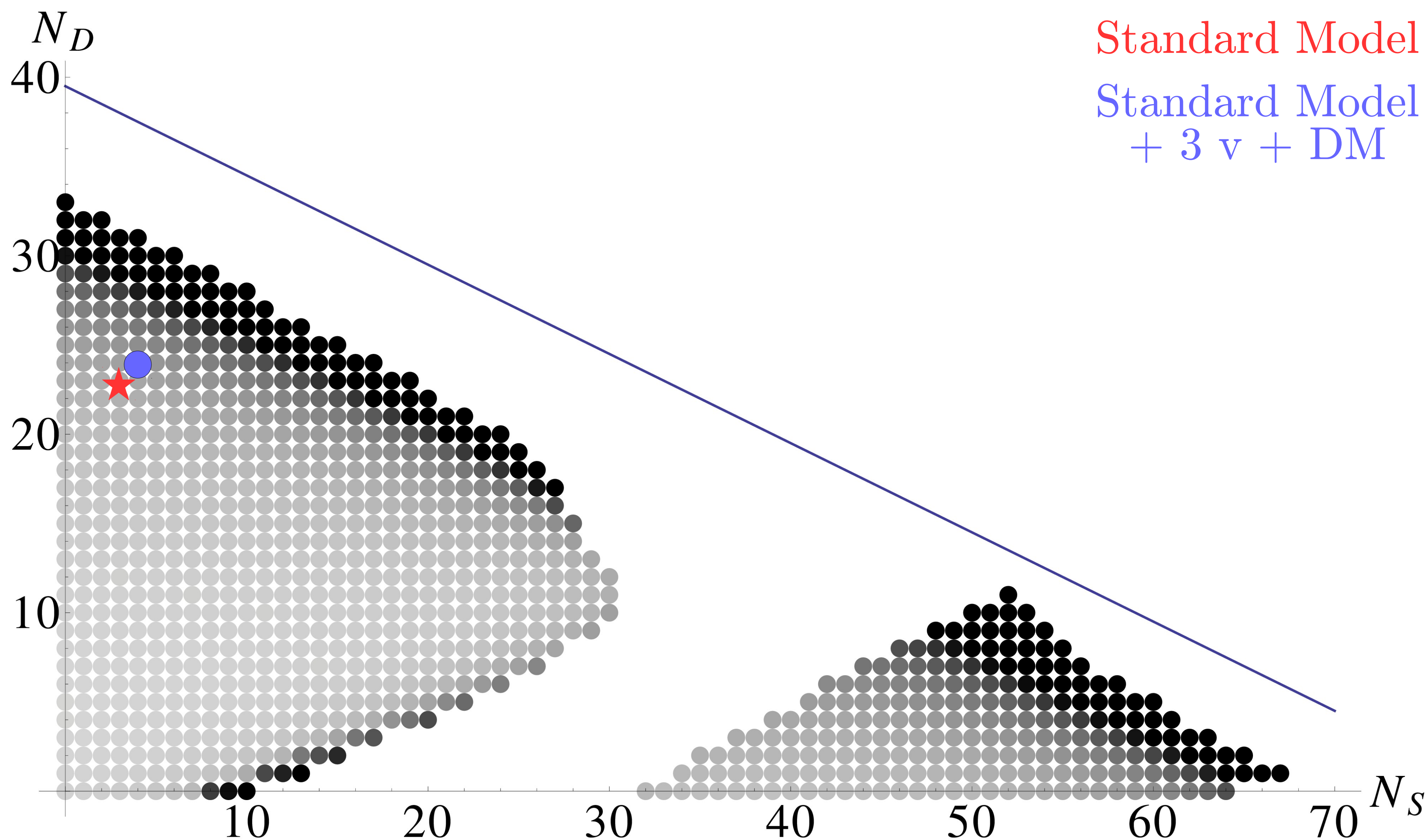

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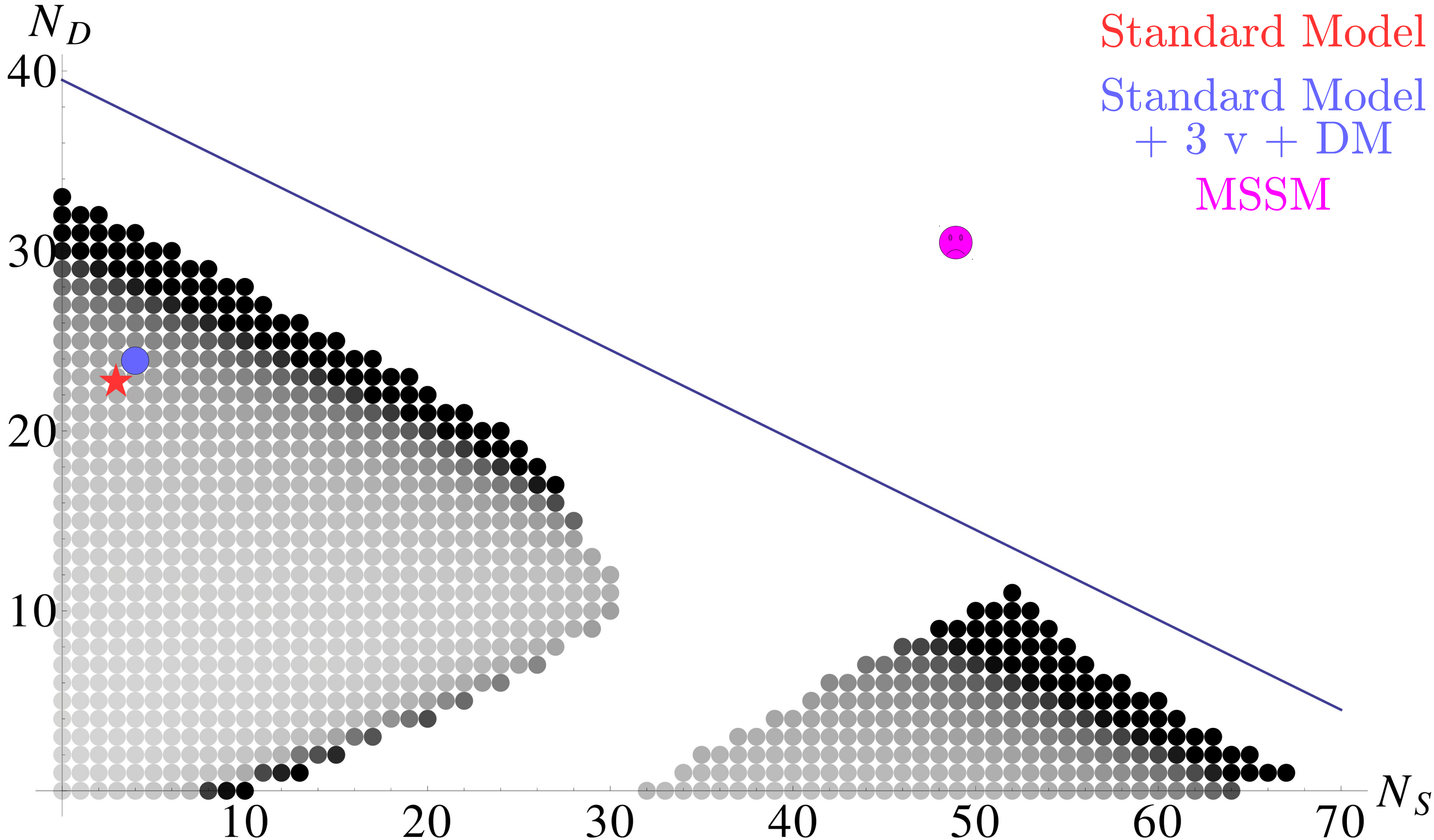

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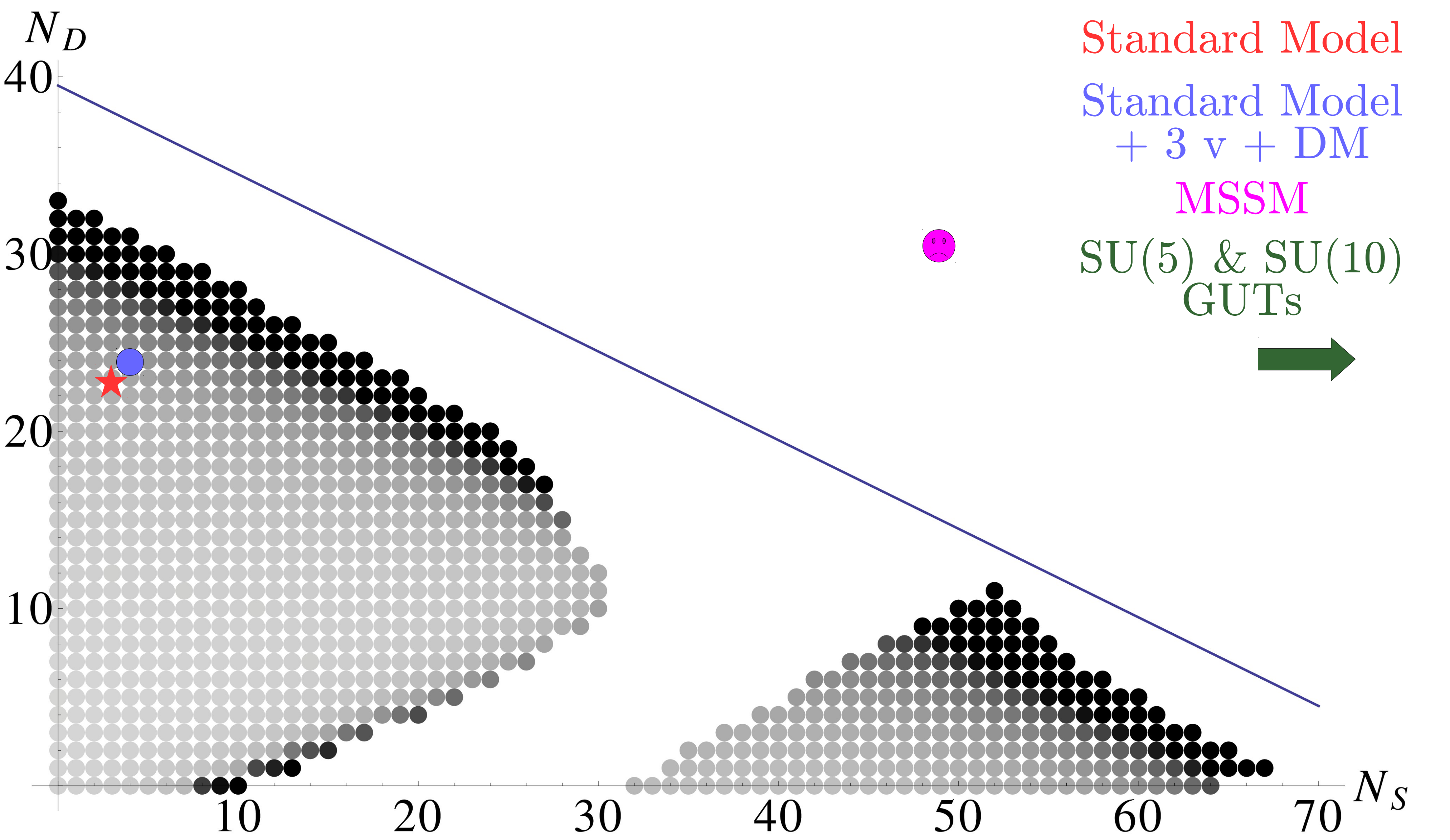
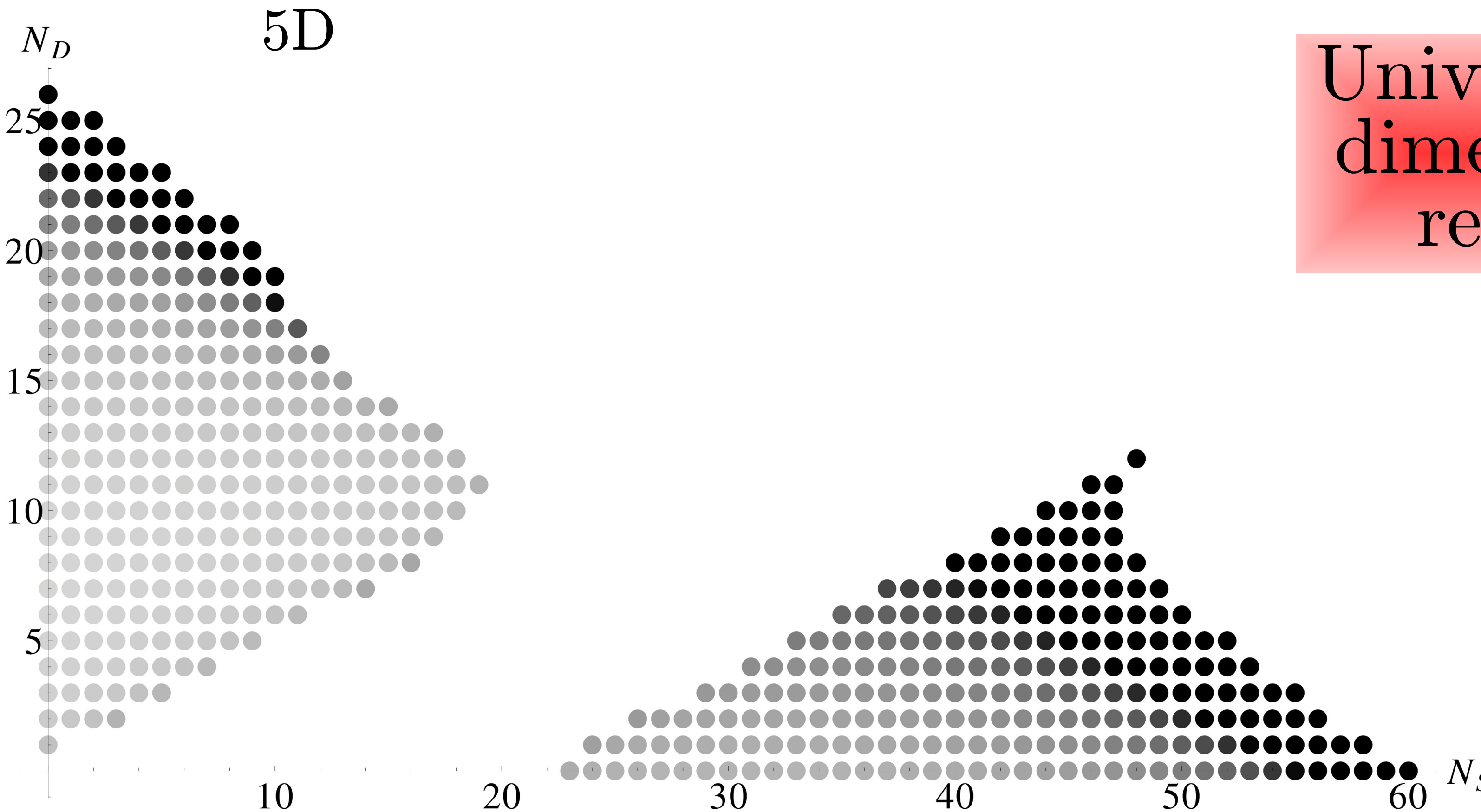
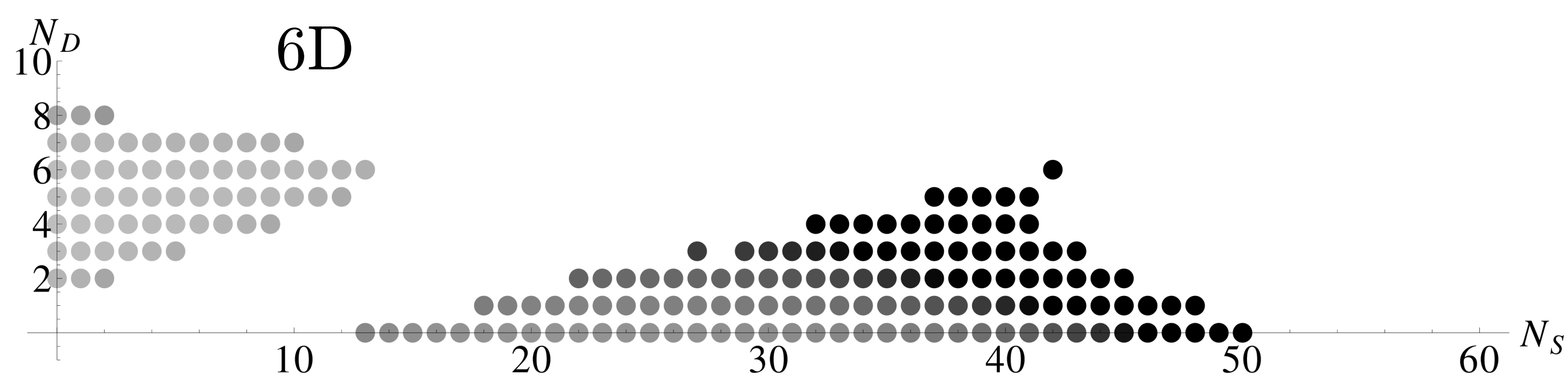


($N_V = 12$)

Extra Dimensions





Universal Extra dimensions are restricted!

Newton couplings

[P.D., A. Eichhorn, P. Labus and R. Percacci arXiv:1512.01589]

$$\int \mathcal{D}h_{\mu\nu} \exp -S\left(\bar{g}_{\mu\nu} + h_{\mu\nu}\right)$$

Shift symmetry

$$\bar{g}_{\mu\nu} \to \bar{g}_{\mu\nu} + \gamma_{\mu\nu}$$

$$h_{\mu\nu} \to h_{\mu\nu} - \gamma_{\mu\nu}$$

Explicitly broken!

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Gravity:

$$-\frac{1}{16\pi G_0}\int \mathrm{d}^d x\, \sqrt{\bar{g}}\bar{R} + \frac{1}{16\pi G_2}\int \mathrm{d}^d x\, \sqrt{\bar{g}} h_{\mu\nu} K^{\mu\nu\rho\sigma}\left(-\bar{D}^2\right) h_{\rho\sigma}$$

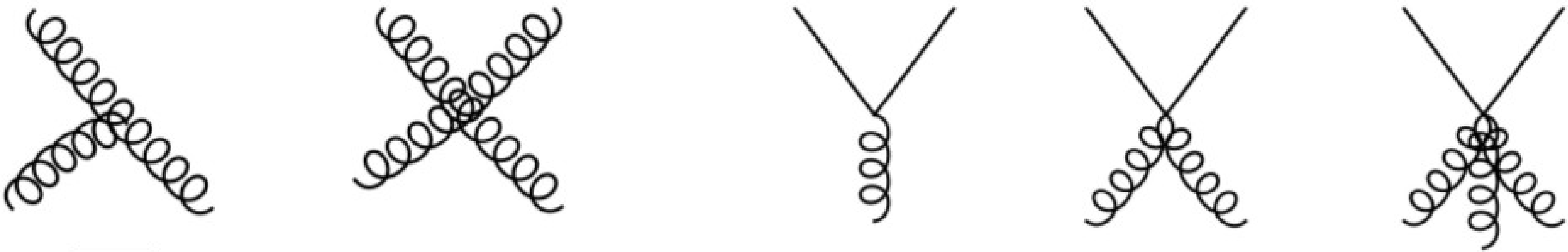
$$+\frac{1}{16\pi G_3}\int \mathrm{d}^d x\, \sqrt{\bar{g}} h_{\mu\nu} T^{\mu\nu\rho\sigma\kappa\lambda} h_{\rho\sigma} h_{\kappa\lambda} + \frac{1}{16\pi G_4}\int \mathrm{d}^d x\, \sqrt{\bar{g}} h_{\mu\nu} h_{\alpha\beta} T^{\mu\nu\rho\sigma\kappa\lambda\alpha\beta} h_{\rho\sigma} h_{\kappa\lambda}$$

What is the Newton Constant?

Newton couplings

[P.D., A. Eichhorn, P. Labus and R. Percacci arXiv:1512.01589]

Gravity + Minimally coupled massless scalars



$\sqrt{G_3}$ $\quad G_4 \quad$ $\sqrt{g_3}$ $\quad g_4 \quad$ $g_5^{3/2}$

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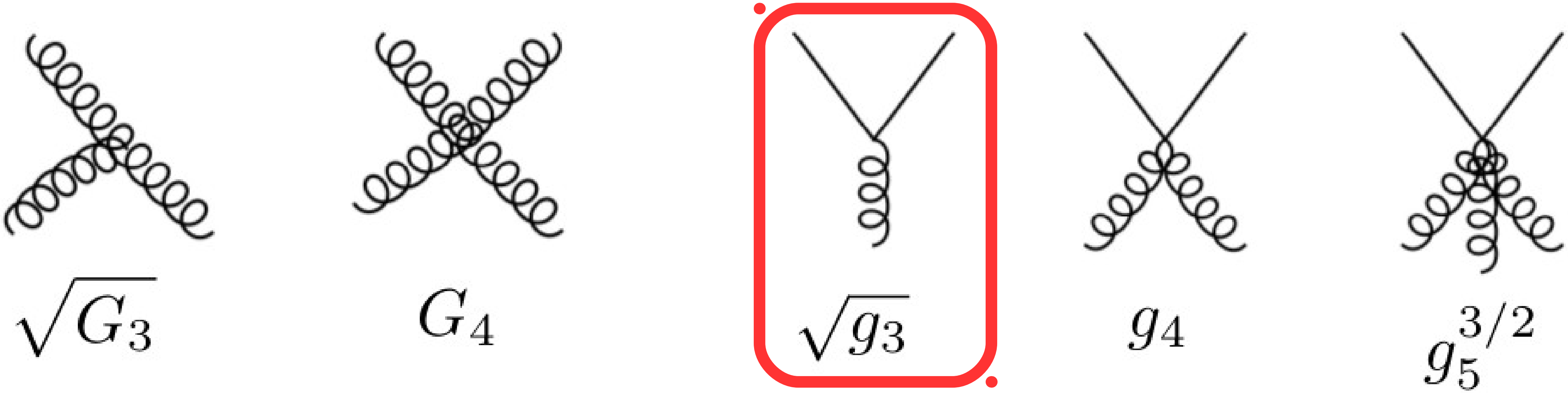

$$
\begin{aligned}
\beta_{g_3} = &\,(2+\eta_{\mathrm{TT}}+2\eta_S)\,g_3 + \frac{3}{2\pi}g_3^2 + \frac{3}{2\pi}g_3^{3/2}\sqrt{G_3} - \frac{4}{\pi}g_3 g_4 - \frac{5}{18\pi}g_5^{3/2}\sqrt{g_3} \\
&+\left(-\frac{5}{54\pi}g_4\sqrt{G_3} + \frac{23}{108\pi}g_5^{3/2}\right)\sqrt{g_3}\,\eta_{\mathrm{TT}} + \left(\frac{-1}{20\pi}g_3^{3/2} - \frac{1}{10\pi}g_3\sqrt{G_3} + \frac{1}{4\pi}\sqrt{g_3}\,g_4\right. \\
&\left.+\frac{5}{54\pi}g_4\sqrt{G_3} - \frac{1}{6\pi}g_5^{3/2}\right)\sqrt{g_3}\,\eta_\sigma + \left(-\frac{1}{10\pi}g_3^{3/2} - \frac{1}{20\pi}g_3\sqrt{G_3} + \frac{1}{4\pi}\sqrt{g_3}\,g_4\right)\sqrt{g_3}\,\eta_S
\end{aligned}
$$

- Exponential parametrization
- Distinction between scalar and TT component of the graviton

Newton couplings

[P.D., A. Eichhorn, P. Labus and R. Percacci arXiv:1512.01589]

Pure gravity limit (no scalar fluctuations)

$g_5 = g_4 = G_3 = G_4 = g_3$

$g_{3*} = 4.58 \quad \theta = 2.27$

$\eta_{TT} = -1.24 \quad \eta_\sigma = 1.32$

$\bar{G}_* = 3.68 \quad \theta = 2$

[G. Vacca and R. Percacci 2015]

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[G. Vacca and
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Including scalar fluctuations

$$g_5 = g_4 = G_3 = G_4 = g_3$$

$$\beta_{g_3} = 2g_3 - \frac{13}{6\pi}g_3^2 + N_S\frac{1}{24\pi}g_3^2 + 2g_3\eta_S + \dots \qquad \eta_s = \frac{7}{4\pi}g_3$$

$$N_S = 1: \quad g_3* = -7.2 \quad \theta = 1.18$$
$$\eta_{TT} = 1.88 \quad \eta_\sigma = -0.76 \quad \eta_S = -3.67$$

$N_S = 1.8:$ fixed point annihilation

Conclusions

Matter matters in (asymptotically safe) quantum gravity

Asymptotic safety only viable for standard model and “small” extensions within truncated RG flow (unless assume very large number of vectors)

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Thank you for your attention!