Smallness of neutrino mass from trans-Planckian asymptotic safety

Enrico Maria Sessolo

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in collaboration with
Kamila Kowalska and Soumita Pramanick

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SONATA BIS 10 (PI: E.M.Sessolo)
SONATA BIS 7 (PI: K. Kowalska)

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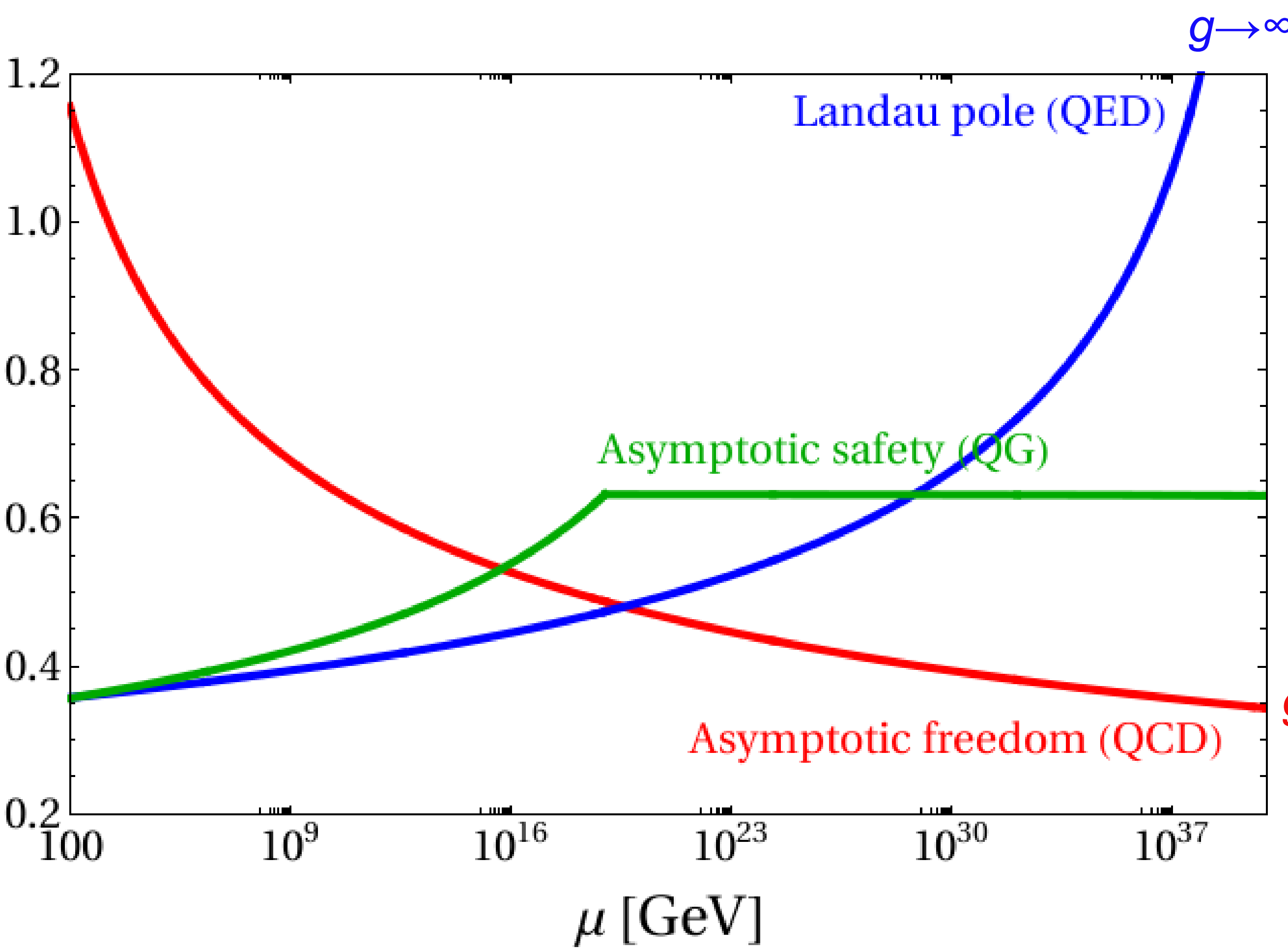
Renormalization group flow

Charge-screening by quantum fluctuations → *running* coupling constants, $g_i(\mu)$



$g^* \neq 0$

$g^* = 0$

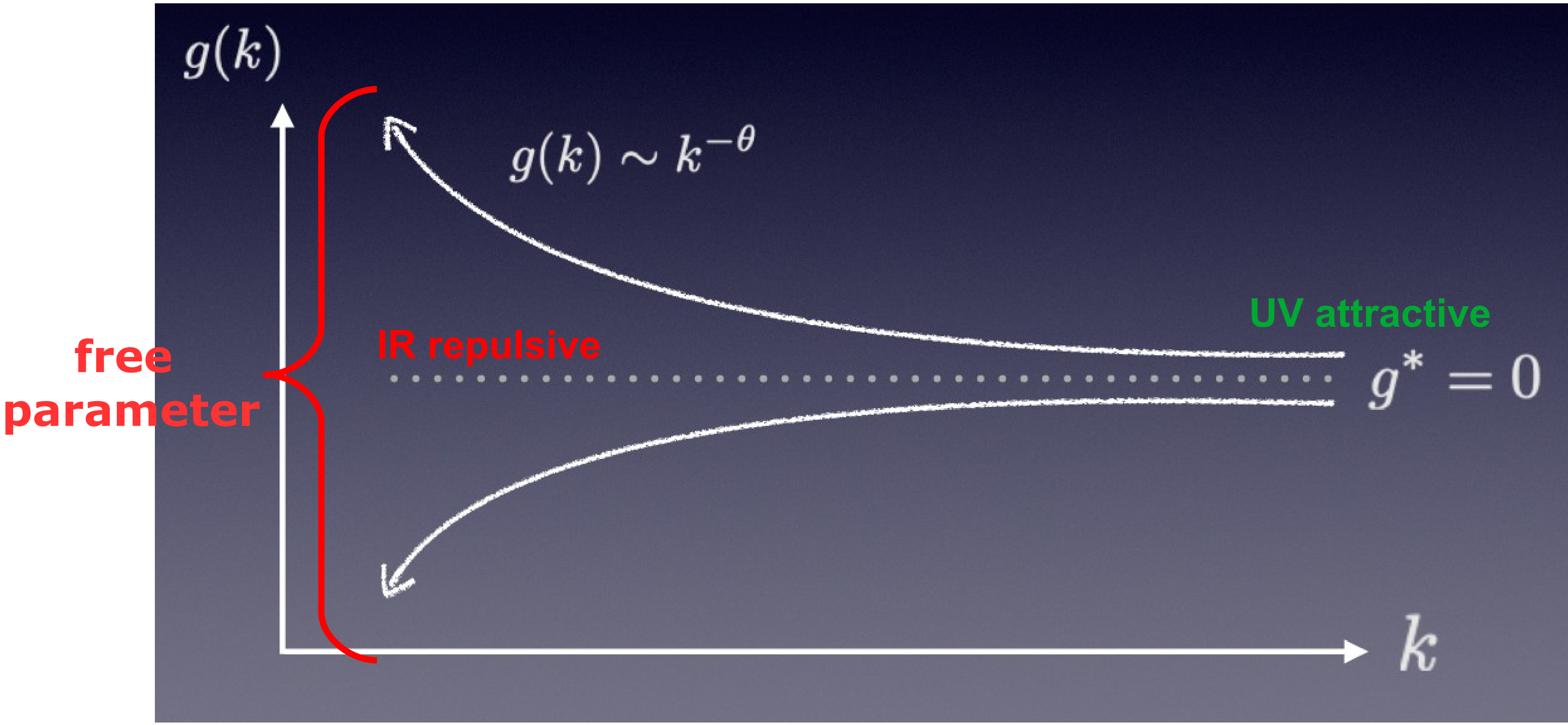
$$\beta_g = \frac{dg}{dt} = \frac{dg}{d\ln\mu}$$

$$\beta_g(g^*) = 0$$

fixed point *g**
in the RG flow

Scaling properties of g_i

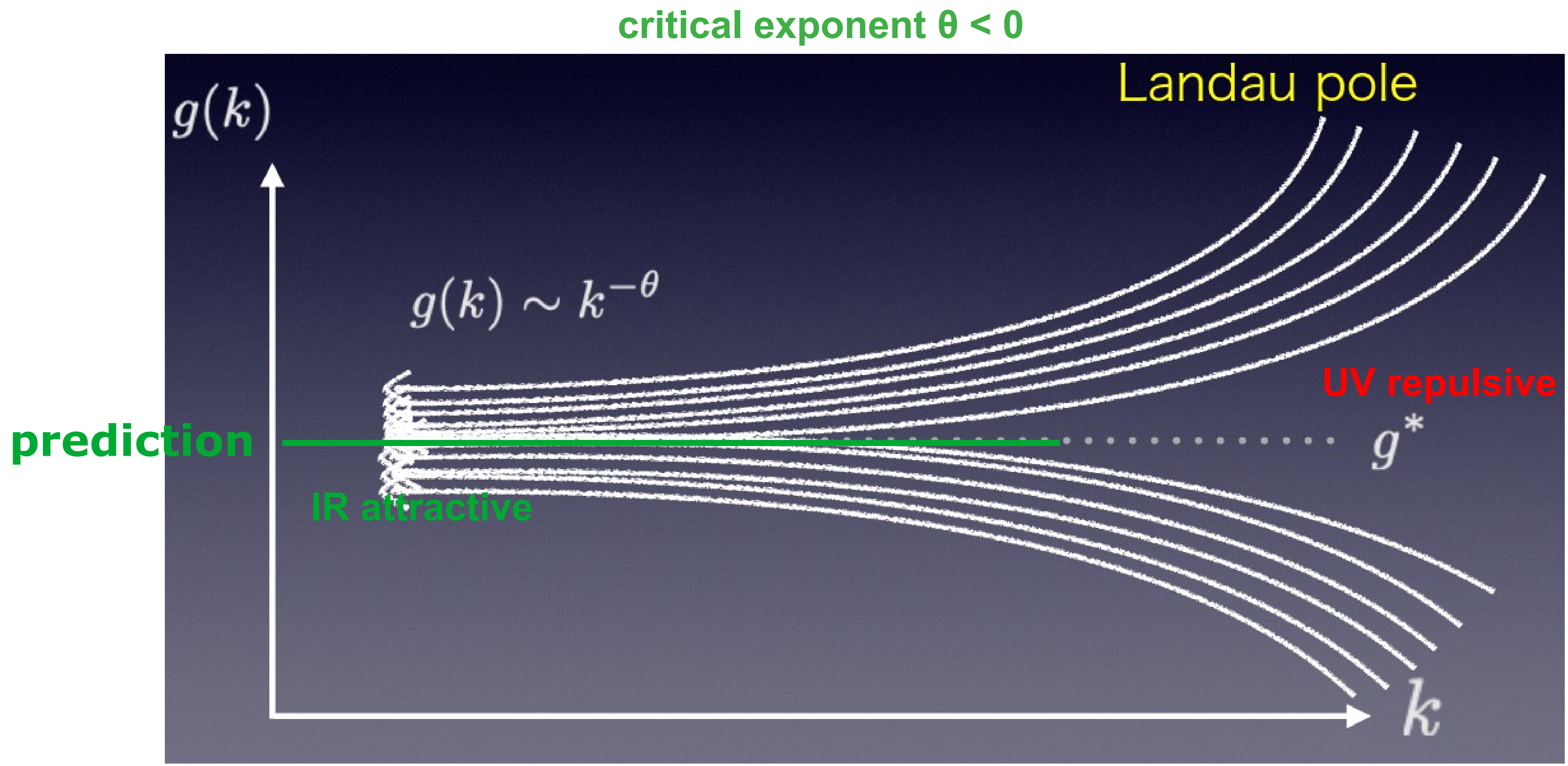
critical exponent θ > 0



M.Yamada, HECA seminar, 08.10.2019

Relevant couplings are free parameters

Scaling properties of g_i



M.Yamada, HECA seminar, 08.10.2019

Irrelevant couplings provide **predictions**

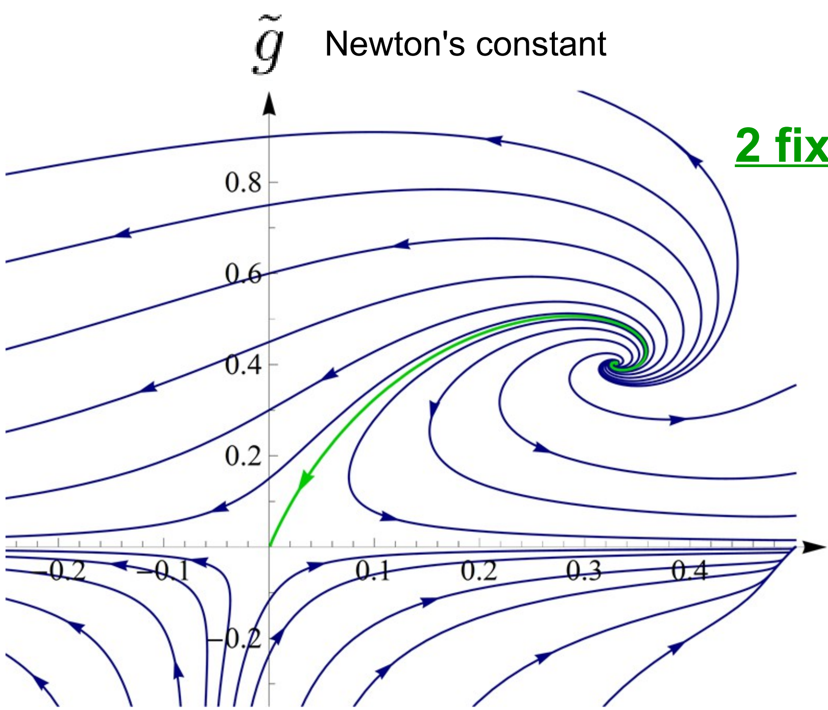
QFTs with fixed points

Quantum gravity might feature interactive UV fixed points
(functional renormalization group)

Reuter '96, Reuter, Saueressig '01, Litim '04, Codello, Percacci, Rahmede '06, Benedetti, Machado, Saueressig '09, Narain, Percacci '09, Manrique, Rechenberger, Saueressig '11, Falls, Litim, Nikolakopoulos '13, Dona', Eichhorn, Percacci '13, Daum, Harst, Reuter '09, Folkerst, Litim, Pawlowski '11, Harst, Reuter '11, Zanusso *et al.* '09 … many more

$$\Gamma_k = -\frac{1}{16\pi G_N}\int d^4x \sqrt{g}\left(R - 2\bar{\Lambda}\right) \qquad \tilde{g} = G_N k^2\,, \quad \tilde{\lambda} = \bar{\Lambda} k^{-2}$$

scale dependence



Reuter, Saueressig
Phys.Rev.D 65 (2002) 065016

QFTs with fixed points

Quantum gravity plus matter

Christiansen, Eichhorn '17, Christiansen *et al.* '17, Shaposhnikov, Wetterich '09, Oda, Yamada '15, Eichhorn, Held, Pawlowski '16, Wetterich, Yamada '16, Hamada, Yamada '17, Pawlowski *et al.* '18, Eichhorn, Versteegen '17, Eichhorn, Held '17-'18 …

Beta functions of the SM:

hypercharge

$$\frac{dg_Y}{dt} = \frac{g_Y^3}{16\pi^2}\frac{41}{6}$$

weak

$$\frac{dg_2}{dt} = -\frac{g_2^3}{16\pi^2}\frac{19}{6}$$

strong

$$\frac{dg_3}{dt} = -\frac{g_3^3}{16\pi^2}7$$

Yukawa couplings

$$\frac{dy_t}{dt} = \frac{y_t}{16\pi^2}\left(\frac{9}{2}y_t^2 + \frac{3}{2}y_b^2 + 3y_s^2 + 3y_c^2 - \frac{9}{4}g_2^2 - 8g_3^2 - \frac{17}{12}g_Y^2 + y_e^2 + y_\mu^2 + y_\tau^2\right)$$

$$\frac{dy_b}{dt} = \frac{y_b}{16\pi^2}\left(\frac{9}{2}y_b^2 + \frac{3}{2}y_t^2 + 3y_s^2 + 3y_c^2 - \frac{9}{4}g_2^2 - 8g_3^2 - \frac{5}{12}g_Y^2 + y_e^2 + y_\mu^2 + y_\tau^2\right)$$

…. other quarks and leptons ...

QFTs with fixed points

Quantum gravity plus matter

Christiansen, Eichhorn '17, Christiansen *et al.* '17, Shaposhnikov, Wetterich '09, Oda, Yamada '15, Eichhorn, Held, Pawlowski '16, Wetterich, Yamada '16, Hamada, Yamada '17, Pawlowski *et al.* '18, Eichhorn, Versteegen '17, Eichhorn, Held '17-'18 …

Correction due to strong gravity:

hypercharge

$$\frac{dg_Y}{dt} = \frac{g_Y^3}{16\pi^2}\frac{41}{6} - f_g\, g_Y$$

weak

$$\frac{dg_2}{dt} = -\frac{g_2^3}{16\pi^2}\frac{19}{6} - f_g\, g_2$$

strong

$$\frac{dg_3}{dt} = -\frac{g_3^3}{16\pi^2}7 - f_g\, g_3$$

Yukawa couplings

$$\frac{dy_t}{dt} = \frac{y_t}{16\pi^2}\left(\frac{9}{2}y_t^2 + \frac{3}{2}y_b^2 + 3y_s^2 + 3y_c^2 - \frac{9}{4}g_2^2 - 8g_3^2 - \frac{17}{12}g_Y^2 + y_e^2 + y_\mu^2 + y_\tau^2\right) - f_y\, y_t$$

$$\frac{dy_b}{dt} = \frac{y_b}{16\pi^2}\left(\frac{9}{2}y_b^2 + \frac{3}{2}y_t^2 + 3y_s^2 + 3y_c^2 - \frac{9}{4}g_2^2 - 8g_3^2 - \frac{5}{12}g_Y^2 + y_e^2 + y_\mu^2 + y_\tau^2\right) - f_y\, y_b$$

…. other quarks and leptons ...

$$f_g = \tilde{g}\frac{1-4\tilde{\lambda}}{4\pi(1-2\tilde{\lambda})^2}$$

$$f_y = \frac{96+\tilde{\lambda}[-235+\tilde{\lambda}(103+56\tilde{\lambda})]}{12\pi[3+2\tilde{\lambda}(-5+4\tilde{\lambda})]^2}\tilde{g}$$

QFTs with fixed points

Quantum gravity plus matter

Christiansen, Eichhorn '17, Christiansen *et al.* '17, Shaposhnikov, Wetterich '09, Oda, Yamada '15, Eichhorn, Held, Pawlowski '16, Wetterich, Yamada '16, Hamada, Yamada '17, Pawlowski *et al.* '18, Eichhorn, Versteegen '17, Eichhorn, Held '17-'18 …

Find the zeroes ...

hypercharge

$$\frac{dg_Y}{dt} = \frac{g_Y^3}{16\pi^2}\frac{41}{6} - f_g\, g_Y = 0$$

weak

$$\frac{dg_2}{dt} = -\frac{g_2^3}{16\pi^2}\frac{19}{6} - f_g\, g_2 = 0$$

strong

$$\frac{dg_3}{dt} = -\frac{g_3^3}{16\pi^2}7 - f_g\, g_3 = 0$$

Yukawa couplings

$$\frac{dy_t}{dt} = \frac{y_t}{16\pi^2}\left(\frac{9}{2}y_t^2 + \frac{3}{2}y_b^2 + 3y_s^2 + 3y_c^2 - \frac{9}{4}g_2^2 - 8g_3^2 - \frac{17}{12}g_Y^2 + y_e^2 + y_\mu^2 + y_\tau^2\right) - f_y\, y_t = 0$$

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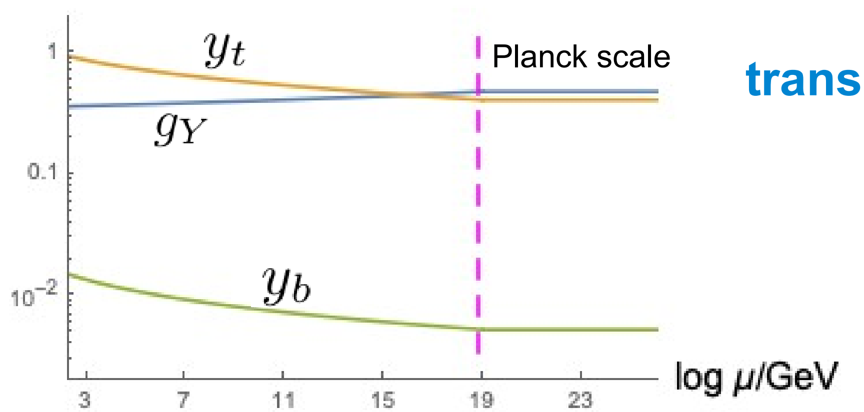


trans-Planckian fixed points of matter!

Comments ...

- **FRG calculation of f_g, f_y has very large uncertainties...**
  (truncation in number of operators, cut-off scheme dependence, etc.)

  Lauscher, Reuter '02, Codello, Percacci, Rahmede '07-'08, Benedetti, Machado, Saueressig '09, Narain, Percacci '09, Dona', Eichhorn, Percacci '13, Falls, Litim, Schroeder '18 ...

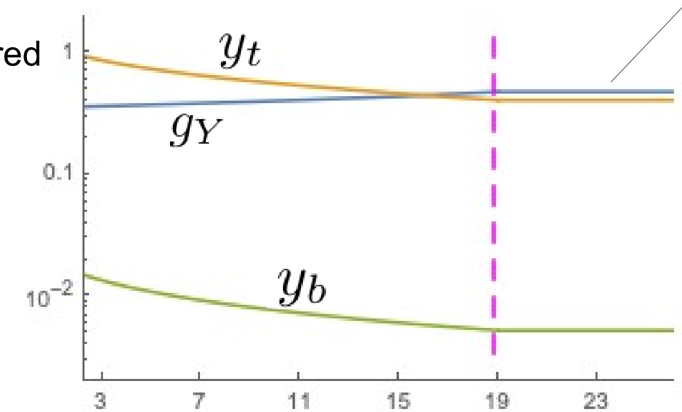
- **FRG calculation is *not required* to get predictions...**

  Wetterich, Shaposhnikov '09, Eichhorn, Held '18, Reichert, Smirnov '19; Alkofer *et al.* '20, Kowalska, EMS, Yamamoto '20, Kowalska, EMS '21, Chikkaballi, Kotlarski, Kowalska, Rizzo, EMS '22 ...

… as the set of *irrelevant* couplings is overconstrained: 3 eqs (g_Y, y_t, y_b)

2 unknowns (f_g, f_y)

measured in IR



log μ/GeV

get f_g

get f_y

Predict y_b

and all other Yukawa couplings...

(in SM or BSM)

Neutrinos

Neutrino masses are very small !

NuFIT5.1 (2021) 2007.14792

$$\Delta m^2_{21} = 7.42^{+0.21}_{-0.20} \times 10^{-5}\,\mathrm{eV}^2,$$
$$\text{NO:} \quad \Delta m^2_{31} = 2.515^{+0.028}_{-0.028} \times 10^{-3}\,\mathrm{eV}^2,$$
$$\text{IO:} \quad \Delta m^2_{32} = -2.498^{+0.028}_{-0.029} \times 10^{-3}\,\mathrm{eV}^2,$$

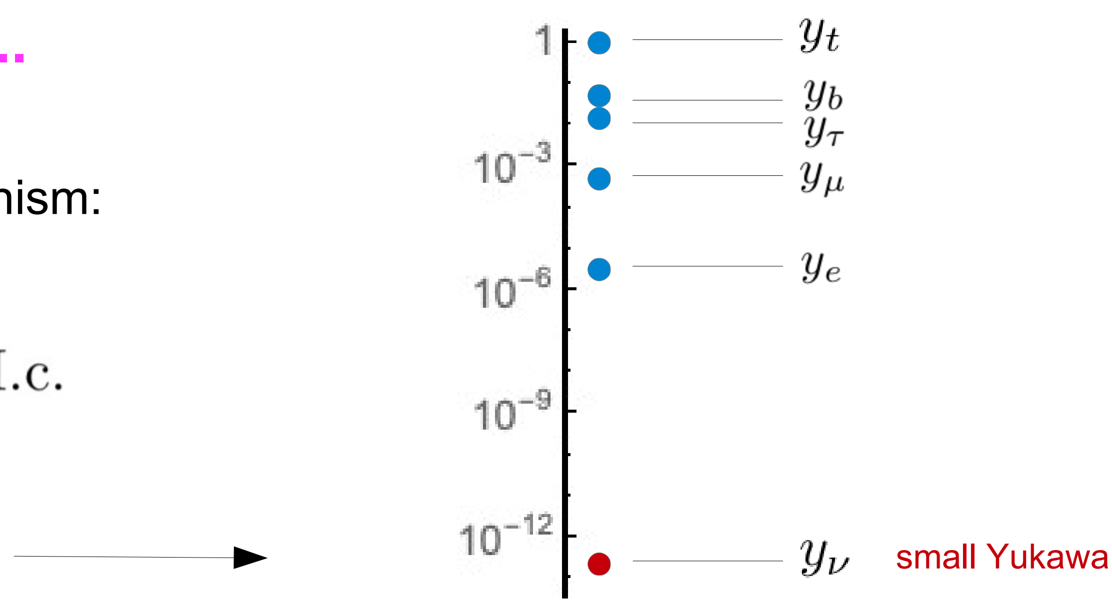
Planck (2021) 1807.06209

$$\sum_{i=1,2,3} m_i < 0.12\,\mathrm{eV}$$

… either Dirac neutrino ...

New Yukawa → Higgs mechanism:

$$\mathcal{L}_D = -y_\nu^{ij}\,\nu_{R,i}\,(H^c)^\dagger L_j + \mathrm{H.c.}$$



Neutrinos

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Planck (2021) 1807.06209

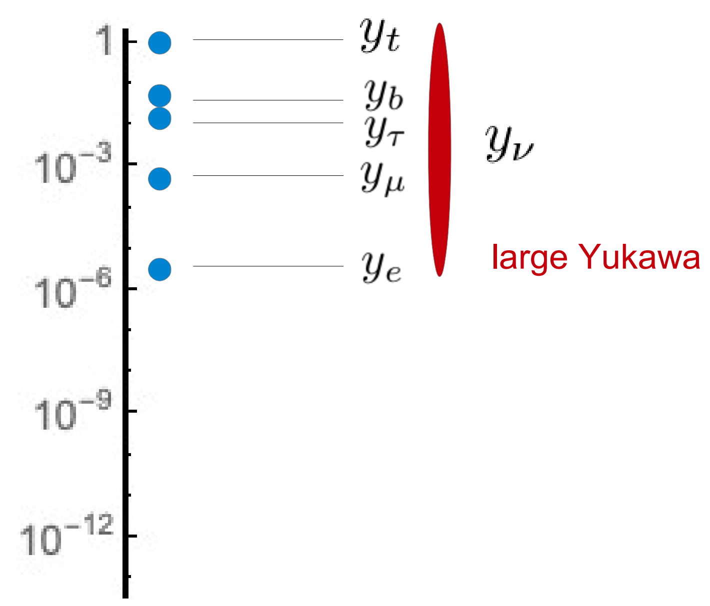
$$\sum_{i=1,2,3} m_i < 0.12\,\mathrm{eV}$$

…. or Majorana neutrino

see-saw mechanism:

$$\mathcal{L}_M = \mathcal{L}_D - \frac{1}{2} M_N^{ij} \nu_{R,i} \nu_{R,j} + \mathrm{H.c.}$$

$$m_\nu \approx \frac{y_\nu^2 v_h^2}{\sqrt{2} M_N}$$



What is predicted?

K.Kowalska, S.Pramanick, EMS
JHEP 08 (2022) 262

Fixed-point analysis:

$$\frac{dg_Y}{dt} = \frac{g_Y^3}{16\pi^2}\frac{41}{6} - f_g\, g_Y \quad \mathbf{= 0} \quad \longrightarrow \text{get } f_g$$

$$\frac{dy_t}{dt} = \frac{y_t}{16\pi^2}\left[\frac{9}{2}y_t^2 + y_\nu^2 - \frac{17}{12}g_Y^2\right] - f_y\, y_t \quad \mathbf{= 0} \quad \longrightarrow \text{get } f_y$$

$$\frac{dy_\nu}{dt} = \frac{y_\nu}{16\pi^2}\left[3y_t^2 + \frac{5}{2}y_\nu^2 - \frac{3}{4}g_Y^2\right] - f_y\, y_\nu \quad \mathbf{= 0} \quad \longrightarrow \text{Predict } y_\nu$$

Two *irrelevant* solutions for the neutrino fixed point:

1. $$y_\nu^{*2} = \frac{32\pi^2}{5}f_y + \frac{3}{10}g_Y^{*2} - \frac{6}{5}y_t^{*2}$$ (interactive)

2. $$y_\nu^* = 0$$ (Gaussian)

What is predicted?

K.Kowalska, S.Pramanick, EMS
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Fixed-point analysis:

$$\frac{dg_Y}{dt} = \frac{g_Y^3}{16\pi^2}\frac{41}{6} - f_g\, g_Y \quad = 0 \quad \rightarrow \text{get } f_g$$

$$\frac{dy_t}{dt} = \frac{y_t}{16\pi^2}\left[\frac{9}{2}y_t^2 + y_\nu^2 - \frac{17}{12}g_Y^2\right] - f_y\, y_t \quad = 0 \quad \rightarrow \text{get } f_y$$

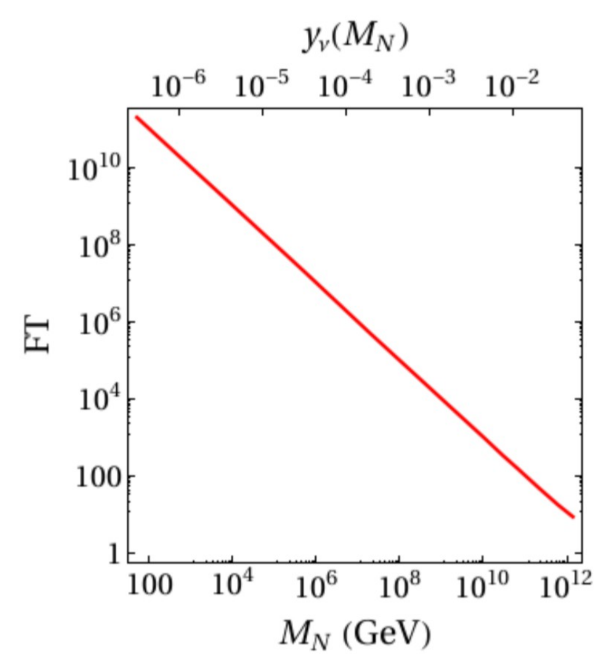
$$\frac{dy_\nu}{dt} = \frac{y_\nu}{16\pi^2}\left[3y_t^2 + \frac{5}{2}y_\nu^2 - \frac{3}{4}g_Y^2\right] - f_y\, y_\nu \quad = 0 \quad \rightarrow \text{Predict } y_\nu$$

Two *irrelevant* solutions for the neutrino fixed point:

1. $$y_\nu^{*2} = \frac{32\pi^2}{5}f_y + \frac{3}{10}g_Y^{*2} - \frac{6}{5}y_t^{*2}$$

large fine tuning of f_y to get small Yukawa

→ **perhaps neutrino is Majorana?**



What is predicted?

K.Kowalska, S.Pramanick, EMS
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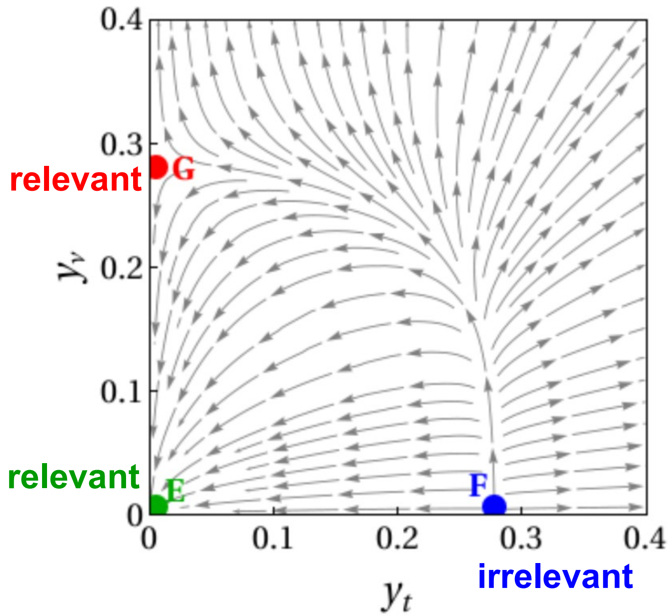
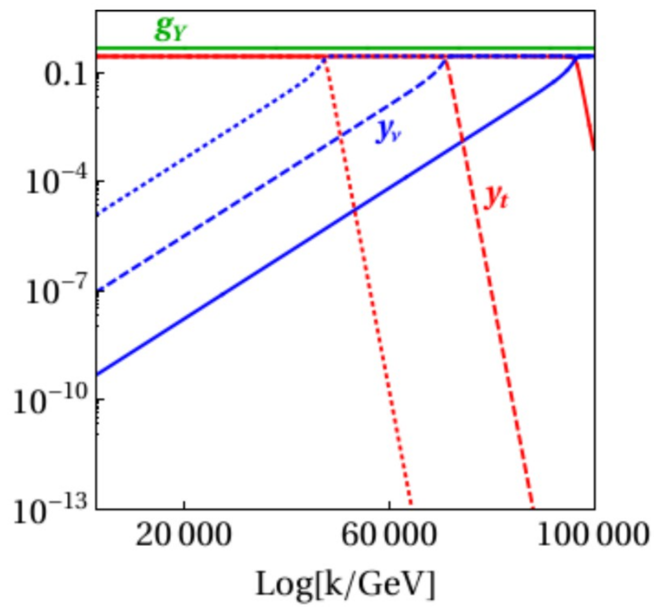
2. $y_\nu^* = 0$ (irrelevant)

… then <u>zero</u> Yukawa coupling is predicted?

Nope (surprise!) ... the system admits **relevant** fixed points too!





$$y_\nu(t;\kappa) \approx \left(\frac{16\pi^2 f_y}{e^{f_y(\kappa - t)} + 5/2}\right)^{1/2}$$

a novel dynamical mechanism (alternative to see-saw)

… smallness of neutrino Yukawa related to the distance of Planck scale from "infinity"

More findings...

K.Kowalska, S.Pramanick, EMS
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- Applies uniquely to neutrino Yukawa coupling (~ quantum singlet)
- This dynamical mechanism stands under the full set of SM RGEs
- It is easily applicable to BSM feebly interacting particles (freeze-in dark matter, pseudo-Dirac neutrinos, ALPs, etc.)