

Insights into the Highest Natural Scale

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Work in progress with

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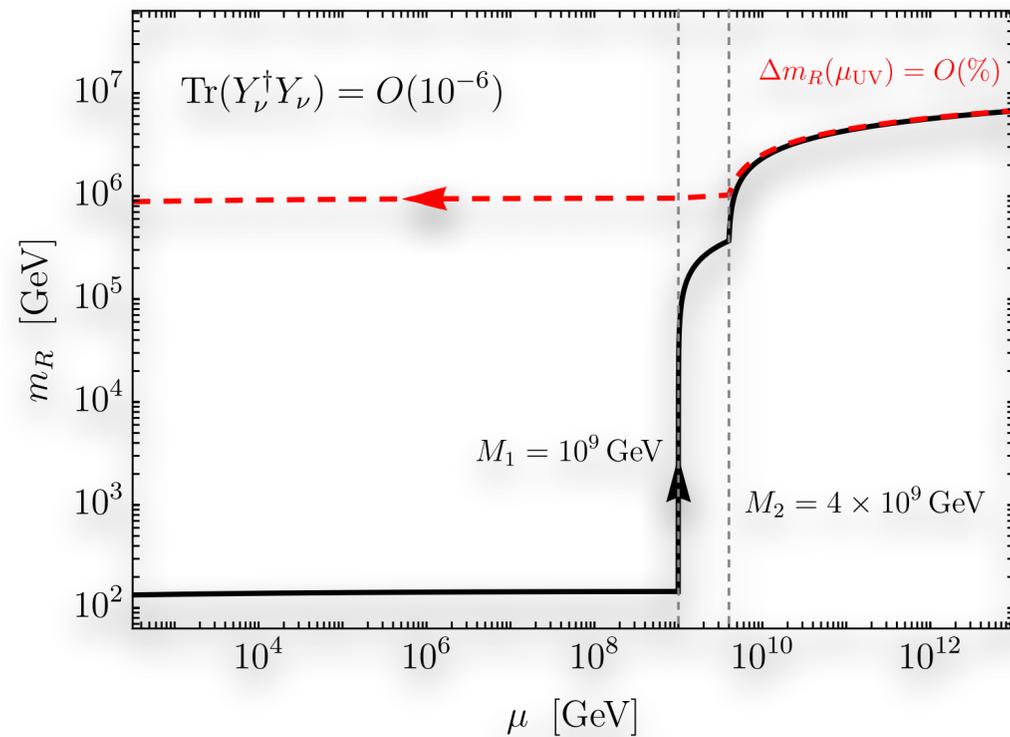


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E.g. right-handed neutrinos

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{2} \bar{\mathcal{N}}_M \left(i\gamma^\mu \partial_\mu - M_R \right) \mathcal{N}_M - Y_\nu \frac{h}{\sqrt{2}} \bar{\nu}_L \mathcal{N}_R + \text{h.c.}$$



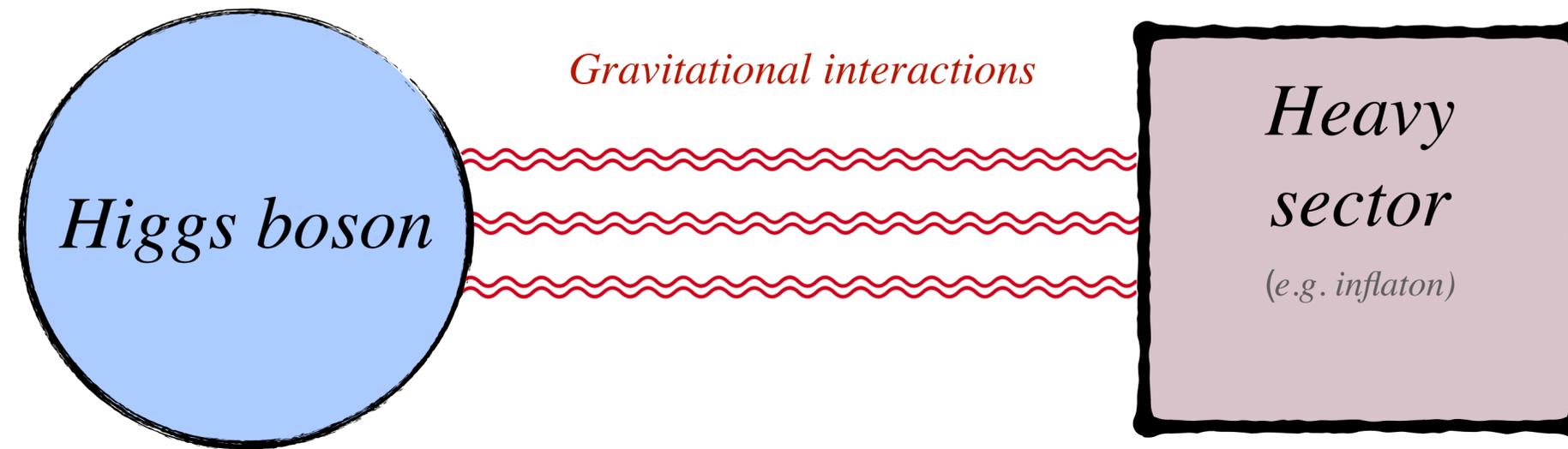
$$\delta m_h^2 \propto \text{---} h \text{---} \text{---} \mathcal{N}_R \text{---} \text{---} h \text{---}$$

$$\frac{dm_R^2}{d \log \mu^2} = \frac{2}{(4\pi)^2} \text{Tr} \left(Y_\nu Y_\nu^\dagger M_R^\dagger M_R \right) + \dots \quad \text{Quadratic sensitivity}$$

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Even in the absence of direct coupling, the Higgs boson is unavoidably coupled to the new heavy scale via the universal force of gravity.

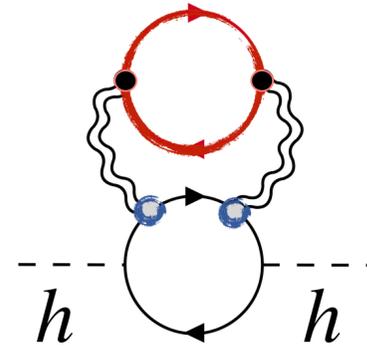


Is there a finite naturalness bound on this heavy sector?

Minimally coupled scalar

$$S = \int d^4x \sqrt{-g} \left[\frac{1}{2} M_{\text{Pl}}^2 R + (D_\mu H)^\dagger (D_\mu H) - V(H^\dagger H) \right]$$

$$\delta m_h^2 \propto \frac{y_t^2}{(16\pi^2)^3} \frac{M_\Psi^4}{M_{\text{Pl}}^4} \times M_\Psi^2$$



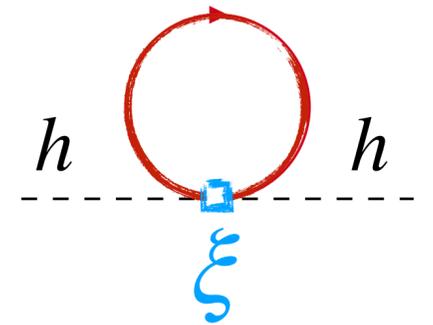
$$M_\Psi \lesssim 10^{14} \text{ GeV}$$

Non-minimally coupled scalar

$$S = \int d^4x \sqrt{-g} \left[\left(\frac{1}{2} M_{\text{Pl}}^2 + \xi H^\dagger H \right) R + (D_\mu H)^\dagger (D_\mu H) - V(H^\dagger H) \right]$$

Generated by quantum fluctuations and consistent with symmetries

$$\delta m_h^2 \propto - \frac{4\xi}{16\pi^2} \frac{M_\Psi^2}{M_{\text{Pl}}^2} \times M_\Psi^2$$



$$\mathcal{O}(1) \text{ number} \quad M_\Psi \lesssim \xi^{-1/4} 10^{10} \text{ GeV}$$

Large field inflationary models with super-Planckian field excursions are disfavored by finite naturalness.