Lepton number, black hole entropy and 10^{32} copies of the SM

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Outline

- Black hole entropy, gravity cutoff & hierarchy problem
- $N = 10^{32}$ copies of the SM
- Neutrino masses in the $N = 10^{32}$ copies SM
- Lepton number violation
- Neutrinoless double beta decay
- Conclusions and perspectives

based on: [S. Kovalenko, H. Päs, I. Schmidt, to be published]

Black hole entropy, gravity cutoff & hierarchy problem

G. Dvali [arXiv:0706.2050] Gedankenexperiment:

- Assume there are N particle species each carrying a separately conserved charge
- N is a big number $\sim 10^{32}$
- Now prepare a black hole containing one particle of each species
- Charge conservation: All particles have to revealed in the BH evaporation process due to Hawking radiation

Black hole entropy, gravity cutoff & hierarchy problem

Black hole thermodynamics:

- A particle of mass Λ can only be emitted if the Hawking temperature is

$$T_H \simeq \frac{M_P^2}{M_{BH}} \gtrsim \Lambda$$

- Energy conservation $\Rightarrow$ maximum number $n_{\max}$ of particles emitted from BH: $n_{\max} = \frac{M_{BH}}{\Lambda}$

- Black hole saturation:

$$N = n_{\max} = \frac{M_P^2}{\Lambda^2}, \qquad \text{or} \qquad M_{\max} = \Lambda$$

Black hole entropy, gravity cutoff & hierarchy problem

Semiclassical lifetime of a BH:

$$\tau_{BH} = \frac{1}{N}\int \frac{1}{T_H^2} dM_{BH} \sim \Lambda^{-1}$$

- BH of size Λ has extremely small lifetime of order $\Lambda^{-}1$
- For energy $E > \Lambda$ the semi-classical treatment breaks down
- For energy $E > \Lambda$ quantum gravity sets in
- The true Planck scale is $\Lambda \simeq \frac{M_P}{\sqrt{N}}$
- For $N = 10^{32} \Rightarrow \Lambda \sim 1$ TeV the Hierarchy problem is solved!
  [Dvali '07,'08]

$N = 10^{32}$ copies SM

Realization - Consider gauge group:

$$\prod_i (SU_{3c} \times SU_{2W} \times U_y)_i \times U_{1(B-L)} \times Z_N$$

- permutation symmetry Z_N acting in the SM$_i$ species space, gauged to be unaffected by black holes (discrete subgroup of some continuous gauge group)
- common anomaly free gauge factor $U_{1(B-L)}$ to prevent dangerous LNV from TeV black holes

Relevant Lagrangian: $\mathcal{L}_{\nu HS} = \lambda_{ij} \overline{\nu_{Rj}} (LH)_i + \beta_{ij} \overline{\nu^c_{Ri}} \nu_{Rj} S + \kappa_i (H^\dagger H)_i S^\dagger S$

[Kovalenko, Päs, Schmidt, to be published]

Neutrino masses

No large scale $\rightarrow$ no seesaw suppression of neutrino masses

Why are neutrinos so light?

Unitarity Argument [Dvali, Redi, arXiv:0905.1709]:

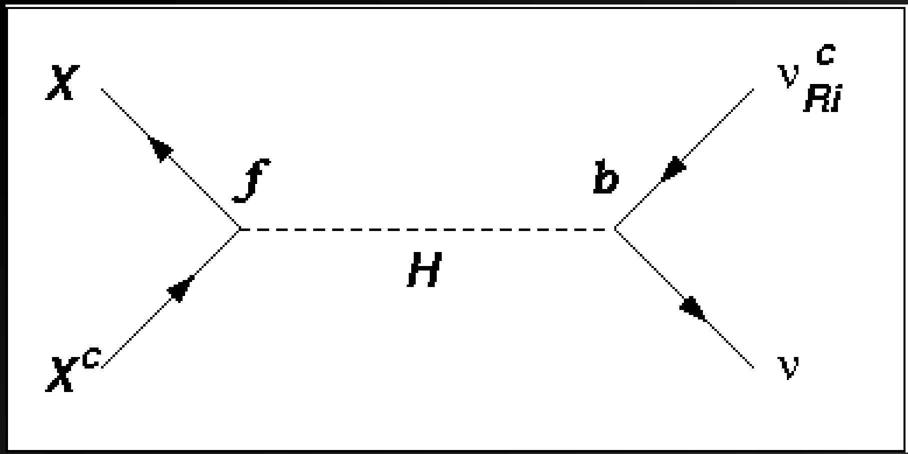
N right-handed neutrino species couple democratically via Dirac Yukawas

$$\lambda_{ij} = \begin{pmatrix} a & b & b & .. \\ b & a & b & .. \\ b & b & a & .. \\ .. & .. & .. & .. \end{pmatrix}$$

[Dvali, Redi, arXiv:0905.1709]

Neutrino masses

Consider right-handed neutrino production from SM particle scattering:



$$\Gamma \simeq N b^2 E \Rightarrow b \lesssim \frac{1}{\sqrt{N}} \Rightarrow m_{\rm Dirac} \propto \frac{1}{\sqrt{N}} \lesssim O(eV)$$

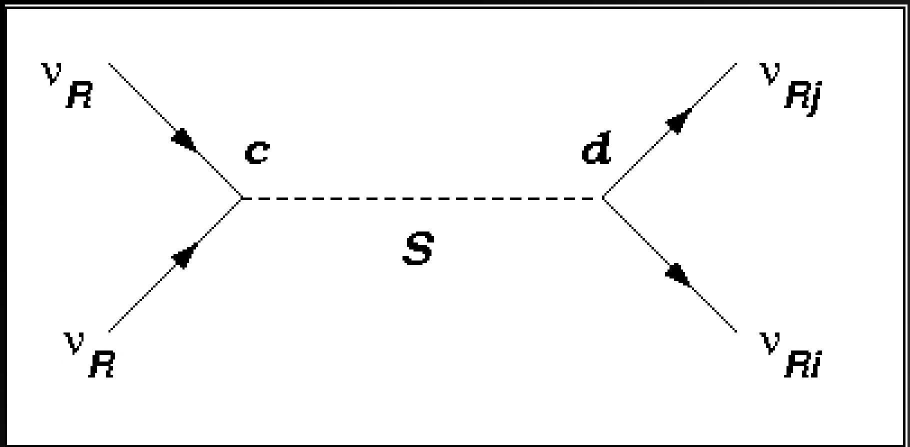
[Dvali, Redi, arXiv:0706.2050]

Neutrino masses

What about Lepton number violation? (ignored by Dvali & Redi)

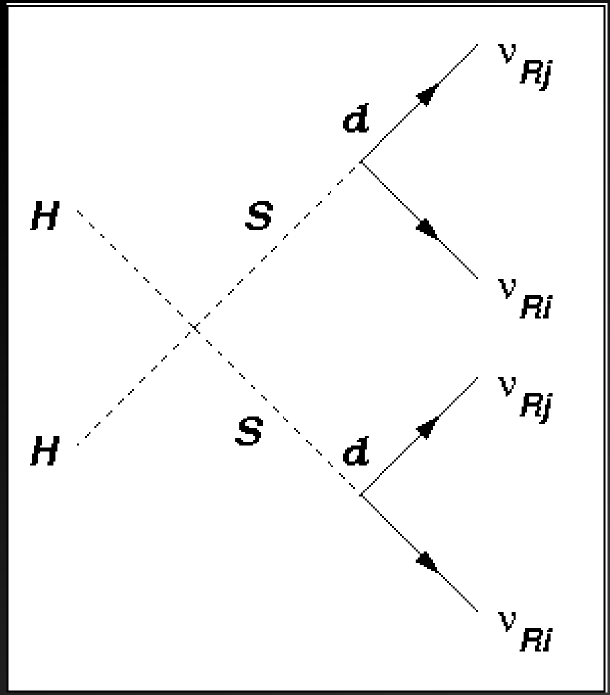
Analogous argument:

$$\beta_{ij} = \begin{pmatrix} c & d & d & .. \\ d & c & d & .. \\ d & d & c & .. \\ .. & .. & .. & .. \end{pmatrix}$$



$$\Gamma \simeq N^2 c^2 d^2 E \qquad \Rightarrow \qquad c \sim d \lesssim \frac{1}{\sqrt{N}}$$

Even stronger constraint from Higgs scattering

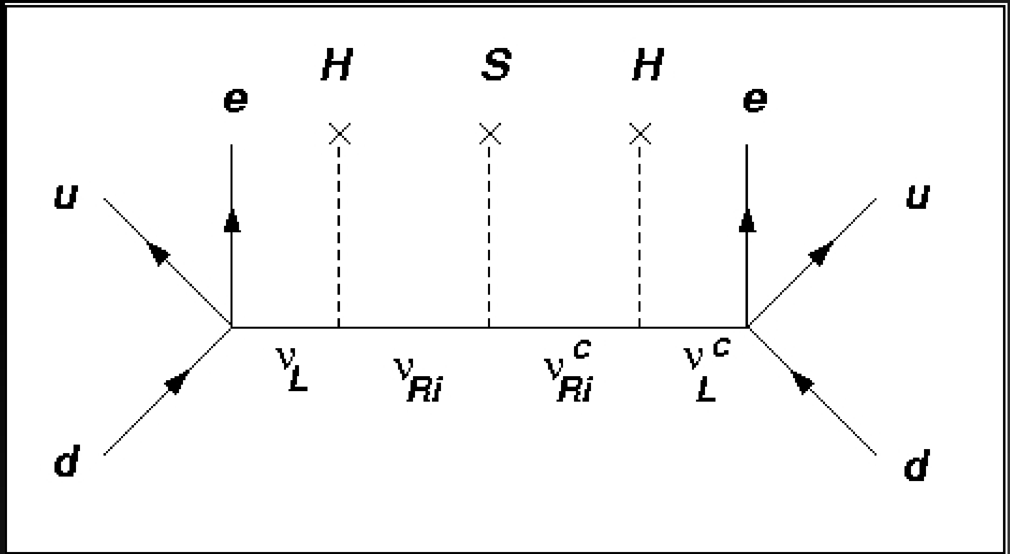


$$\Gamma \simeq N^4 \kappa^2 d^4 E \quad \Rightarrow \quad c \sim d \lesssim \frac{1}{N} \quad \Rightarrow \quad m_{\mathrm{Maj}} \propto \frac{1}{N} \ll m_{\mathrm{Dirac}}$$

[Kovalenko, Päs, Schmidt, to be published]

Neutrinoless double beta decay

Phenomenology? Small couplings vs. many states



Naively one would expect

$$m_{\beta\beta} = m_D \frac{m_M}{p^2} m_D \sim \sqrt{N} \frac{m_D^3}{(100\ \mathrm{MeV})^2}$$

which for $m_D \simeq O(eV)$ and $N \simeq 10^{32}$ would be in the range presently explored by experiments!

Neutrinoless double beta decay

Correct treatment:

Diagonalize $2N \times 2N$ matrix:

$$\mathrm{M}^{\nu} = \begin{pmatrix} 0 & m^D \\ m^D & m^M \end{pmatrix}$$

$\Rightarrow$ results in:

- 2 groups of $N-1$ degenerate states which pair up to Quasi-Dirac neutrinos
- 2 heavy states

[Kovalenko, Päs, Schmidt, to be published]

Neutrinoless double beta decay

LNV is even more suppressed!

Reason: the leading order contribution vanishes due to the follwing facts:

- due to the structure of the mass matrix

$$\sum_k m_k U_{1k}^2 = \mathcal{M}_{11}^{\nu} = 0$$

- The Majorana states contributions of the light states in the sum cancel individually!

Consequence: the dominant contribution scales like $\sim 1/N^2 \rightarrow$ unobservable!

This conclusions still holds if the assumptions $a \sim b$ and $c \sim d$ is relaxed!

Other phenomenological consequences

So the left-handed sector is is safe from LNV

$\Rightarrow$ no LNV phenomenology at all?

Not necessarily:

- Very naive estimate of right-handed neutrino decay diagrams on tree and one-loop level giving rise to leptogenesis:
  - Yukawa coupling $\sim (\sqrt{N})^2$
  - Versus N ν_{Ri} copies contributing potentially to the decay and the ν_{Ri} propagator in the loop diagram

  $\Rightarrow$ May be relevant - to be checked!
- Similar: single ν_{Ri} production at the LHC

Conclusions and Outlook

- The $N = 10^{32}$-copies SM leads to a reduced Planck scale and thus can solve the Hierarchy problem
- It can be argued that neutrino masses (both Dirac and Majorana) are suppressed by small Yukawas resulting from a Unitarity argument
- Typical problem in any low scale quantum gravity scenario: do LNV operators induced by TeV scale black holes invalidate the model?
- Here: avoided due to a non-trivial cancelation mechanism!
- the $N = 10^{32}$-copies SM is safe from LNV in the SM sector!
- Nevertheless: large number of right-handed Majorana states can have interesting phenomenological consequences (leptogenesis, LHC)