Universal Landau Pole

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Outline:

- Do we really need asymptotic freedom?
- Singular unification: the Universal Landau Pole.
- Minimal working model of the Universal Landau Pole.
- Stability of the Higgs Potential.
- Conclusions.

DO WE REALLY NEED ASYMPTOTIC FREEDOM?

- Simplicity: the less parameters - the better $\rightarrow$ unification.
- Asymptotic freedom: the theory is valid up to infinitely high energies.
- BUT what about gravity?
- At the energies of order of Planck scale $M_{Pl} \sim 10^{19}\ GeV$ gravity becomes strongly coupled, concept of points looses its meaning!
- Simplicity + pointless geometry $\rightarrow$ singular unification.

SINGULAR UNIFICATION: UNIVERSAL LANDAU POLE

- We propose a singular unification at the Planck scale: one should find such a generalization of the Standard Model, that under the renormalization group flow ALL gauge couplings meet their common Landau pole at the Planck scale.

$$\boxed{g_{1,2,3}(\mu) \to \infty \text{ at } \mu \to M_{Pl}}$$

- Kinetic terms of ALL gauge fields vanish and they can not propagate anymore.

$$\boxed{\frac{1}{g(\mu)^2} F_{\mu\nu} F^{\mu\nu} \to 0 \text{ at } \mu \to M_{Pl}}$$

MINIMAL WORKING ULP: REQUIREMENTS

- Simplicity: We want to avoid the proliferation of parameters. The gauge group of the Standard Model, $SU(3) \times SU(2) \times U(1)$ as well as the Higgs sector remain unchanged: we add only fermions.

- Stability: quartic coupling of the Higgs field self interaction λ is always positive under the renormalization group flow.

- NO pathological electric charges $\rightarrow$ restrictions on the representations of new fermions.

MINIMAL WORKING ULP: REALIZATION

- We use Dirac mass terms $M\bar{\psi}\psi$ for new fermions and we are looking for a minimal number of them.

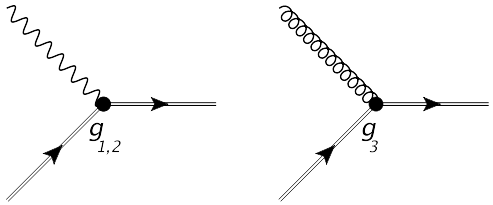
- New paricles are vector-like fermions.

- New fermions belong to known (SM) representations of gauge group

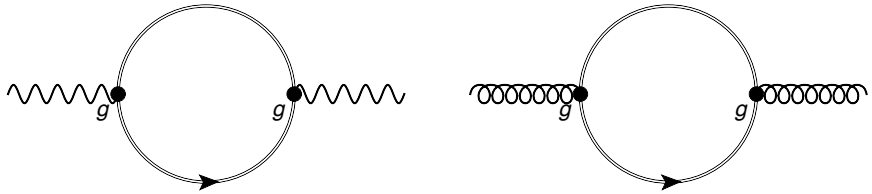
  - L-quarkons: SU(3) - triplets, SU(2) - doublets, $Y = \frac{1}{3}$ c.f. left quarks
  - R-quarkons: SU(3) - triplets, SU(2) - singlets, $Y = \frac{4}{3},\ -\frac{2}{3}$ c.f. right quarks
  - L-leptos: SU(3) - singlets, SU(2) - doublets, $Y = -1$ c.f. left leptons
  - R-leptos: SU(3) - singlets, SU(2) - singlets, $Y = -2,\ 0.$ c.f. right leptons

MINIMAL WORKING ULP: REALIZATION

The only new vertexes appearing in the theory couple Quarkons and Leptos to E-W gauge bosons and gluons.



And at the one loop level only beta functions of gauge fields are modified due to presence of these diagramms:



Running of the gauge couplings is given by:

$$\frac{4\pi}{g^2_{1,2,3}(t)} = -\frac{b_{1,2,3}\cdot(t-t_0)}{2\pi} + \frac{4\pi}{g^2_{1,2,3}(t_0)}, \quad t \equiv \log\frac{\mu}{GeV}$$

$$b_1 = \frac{41}{6} + \frac{2}{3}N_{\mathbf{L-leptos}} + \frac{4}{3}N_{\mathbf{R-leptos}} + \frac{2}{9}N_{\mathbf{L-quarkon}} + \frac{20}{9}N_{\mathbf{R-quarkon}}$$

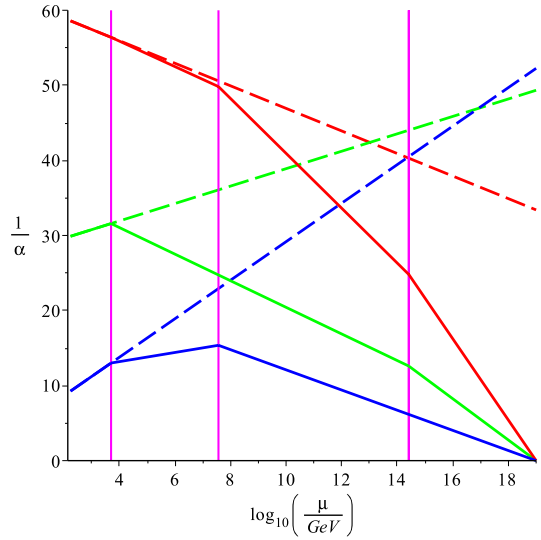
$$b_2 = -\frac{19}{6} + \frac{2}{3}N_{\mathbf{L-leptos}} + 2N_{\mathbf{L-quarkon}}$$

$$b_3 = -7 + \frac{4}{3}\left(N_{\mathbf{L-quarkon}} + N_{\mathbf{R-quarkon}}\right)$$

MINIMAL WORKING ULP: THE ANSWER

- At 5.0 10^3 GeV the L-quarkons ($N_{\mathbf{L-quarkon}} = 4$).
- At 3.7 10^7 GeV the R-quarkons ($N_{\mathbf{R-quarkon}} = 4$).
- At 2.6 10^{14} GeV the L and R-leptos ($N_{\mathbf{L-leptos}} = N_{\mathbf{R-leptos}} = 4$).

For RG running of gauge, top Yukawa and quartic couplings we have:



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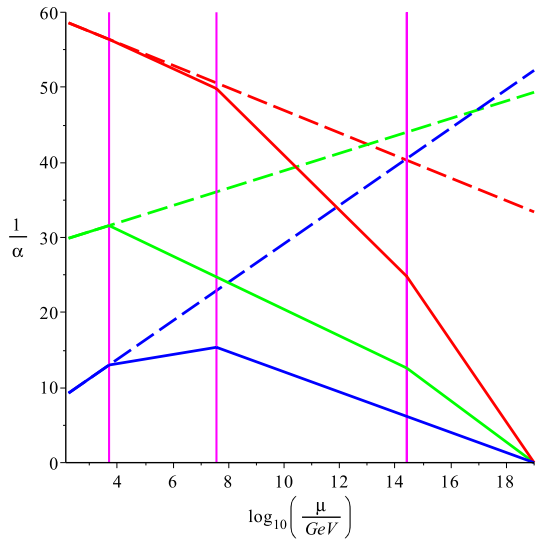

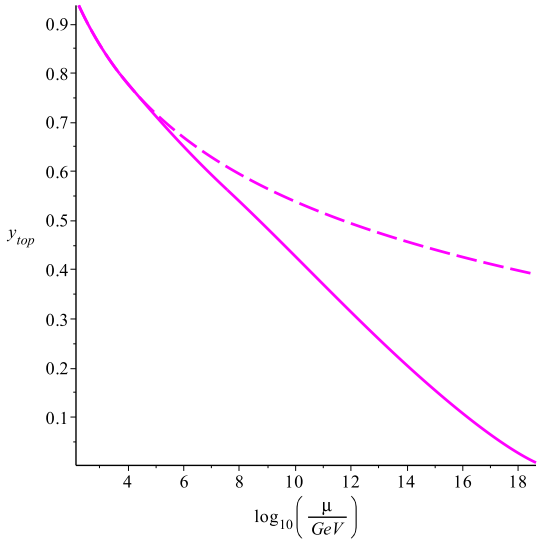

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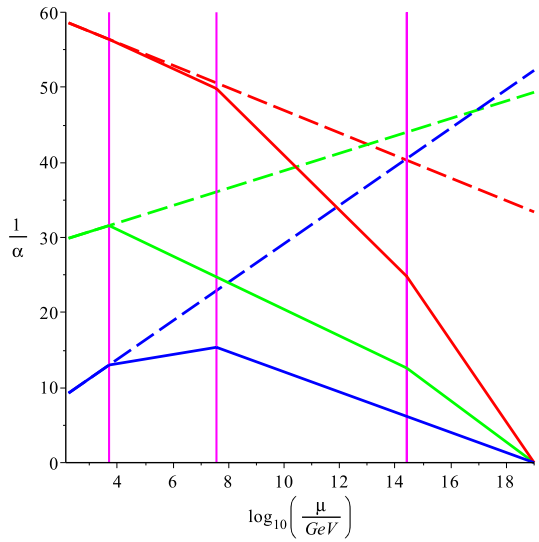
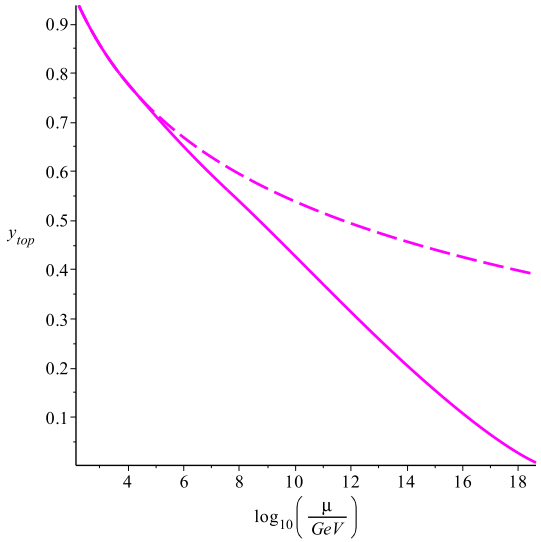
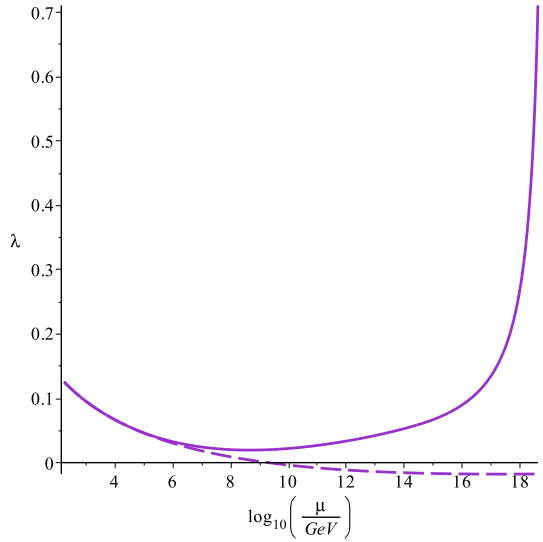


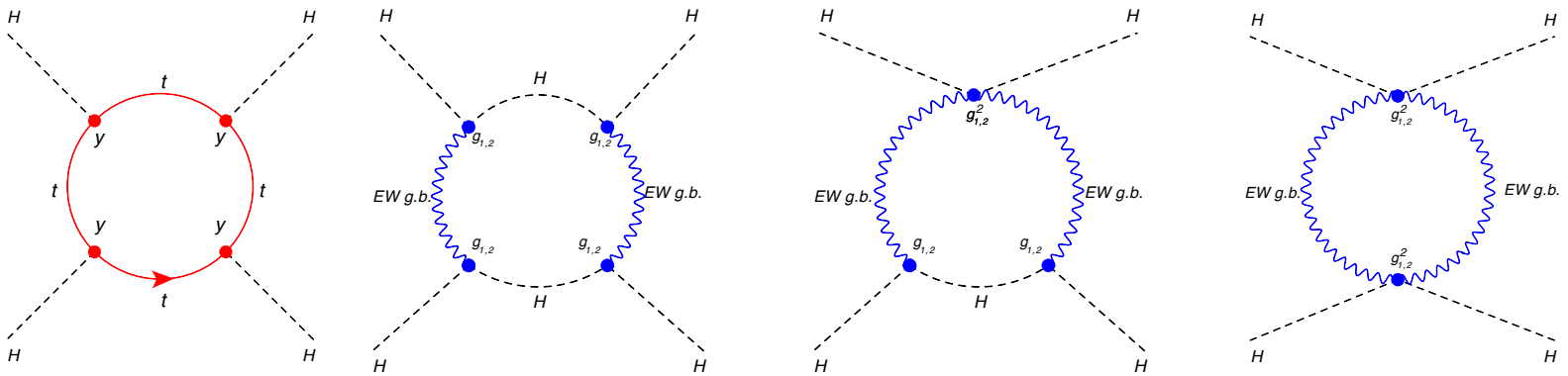




ON THE STABILITY OF THE HIGGS POTENTIAL

Now we clarify how our vector-like fermions save the Universe from instability, i.e. how they don't let RG flow to drive the quartic coupling $\lambda(\mu)$ to negative values.

$$\beta_\lambda^{(1)} = \frac{1}{16\pi^2}\left(24\,\lambda^2 - 6\,y^4 + \frac{3}{4}\,g_2^4 + \frac{3}{8}\left({g_2}^2 + {g_1}^2\right)^2 + \left(-9\,{g_2}^2 - 3\,{g_1}^2 + 12\,y^2\right)\lambda\right).$$



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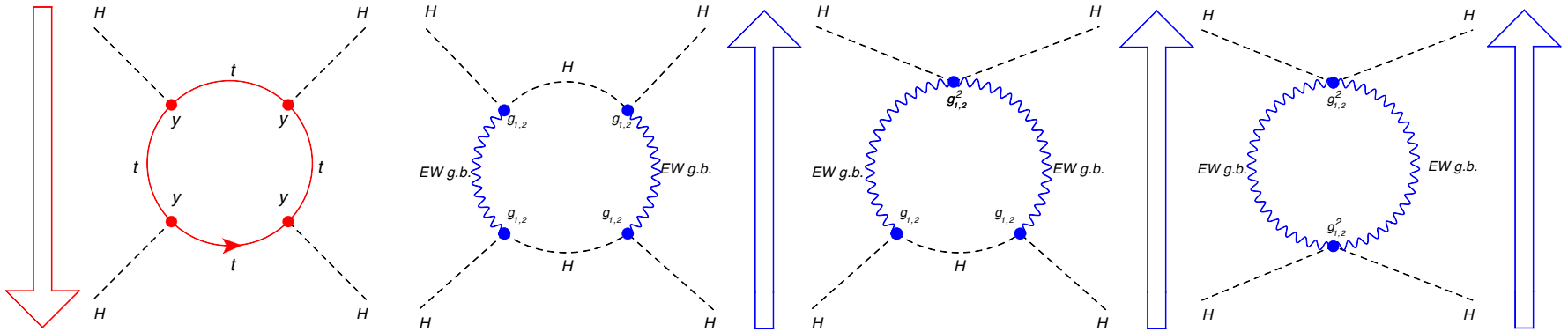

CONCLUSIONS

- An idea of singular unification of ALL gauge interactions at the Planck scale, is proposed in the form of the Universal Landau Pole (ULP).

- The minimal working model of ULP generalization of the SM is constructed.

- Under the RG flow the top Yukawa coupling eventually goes to zero while the quartic coupling has a singularity at the Planck scale. Such a RG behavior saves the Universe from the instability.

THANK YOU FOR YOUR ATTENTION!

COMMENT: ON A UNIQUENESS OF THE SOLUTION

- System of three linear equations for four unknown variables

- Consistence of the scheme $\rightarrow$ the mass hierarchy is fixed:
  L **quarkon**, R **quarkon**, L **leptos**, R **leptos**

- The only ambiguity: number N of "generations" of multiplets of new particles and an order of trasholds

- Stability $\rightarrow N = 3$