Natural Ultraviolet Complete Extensions of the Standard Model

Luca Zambelli

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QFTs & Predictivity

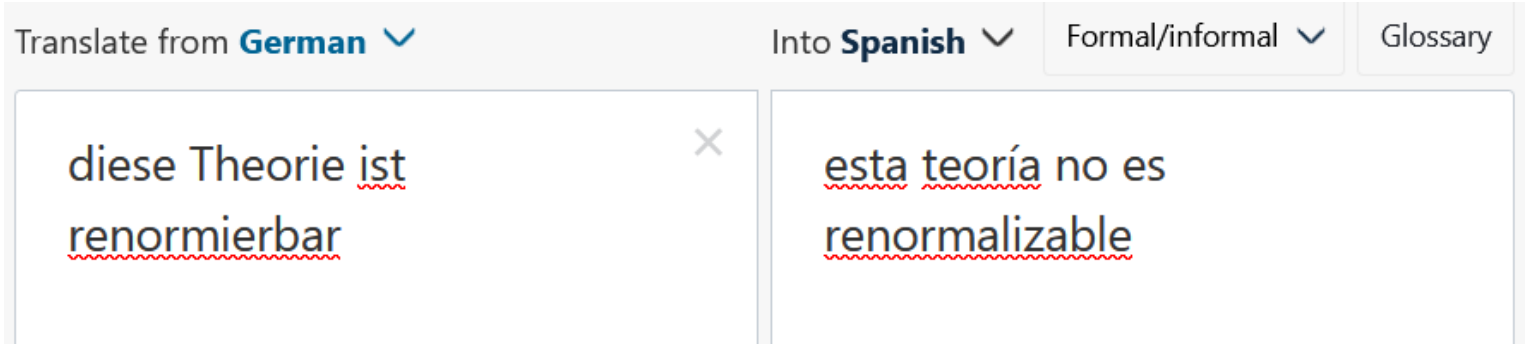
Definitions

- **Predictive Theory**
  given **few** preliminary measurements, is able to predict the result of an ∞ number of experiments
- **Effective Theory**
  predictive only up to a minimum-length/maximum-energy scale (called **UV cutoff**)
- **Ultraviolet Complete (Fundamental) Theory**
  the opposite of an effective theory

QFTs & Predictivity

Two Conflicting Methodological Definitions

- **Perturbatively Renormalizable Theory**
  when it appears to be fundamental within a (all-orders) perturbative series
- **Non-Perturbatively Renormalizable Theory**
  when it appears to be fundamental according to any method which goes beyond the technical limitations of perturbative methods



The RG Flow

A **Renormalization Group (RG)** Transformation:

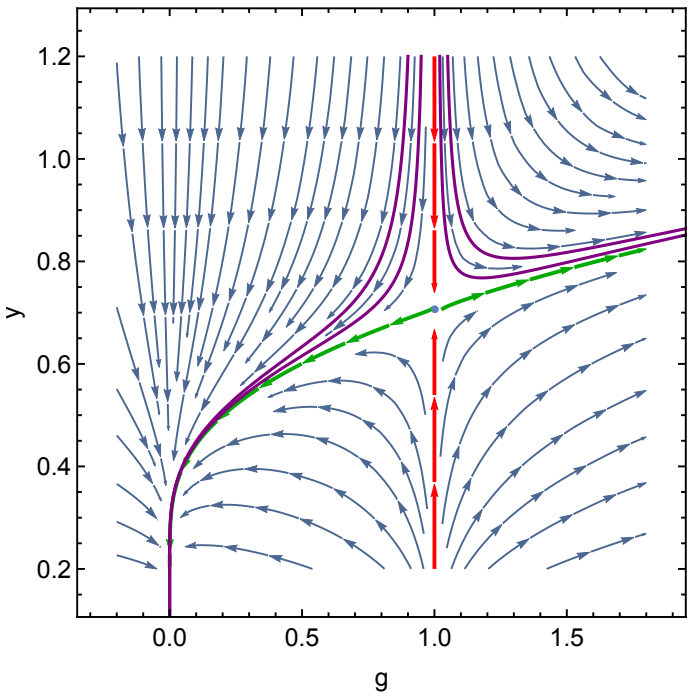
- changes length/energy scales (e.g. the UV cutoff)
- correspondingly changes the theory... (is a mapping between effective theories)
- ...but only its unphysical/unessential features!
- is computable in QFTs!
- is not unique (∞ freedom)

What is it good for?

The RG Flow

It allows to **establish what is physical**:

- the **fixed points of the RG**
  = the theories that do not change at all
- the **stability properties of the fixed points**
- the **long-distance properties**
  = IR attractors = UV complete theories



Wilsonian Renormalizability

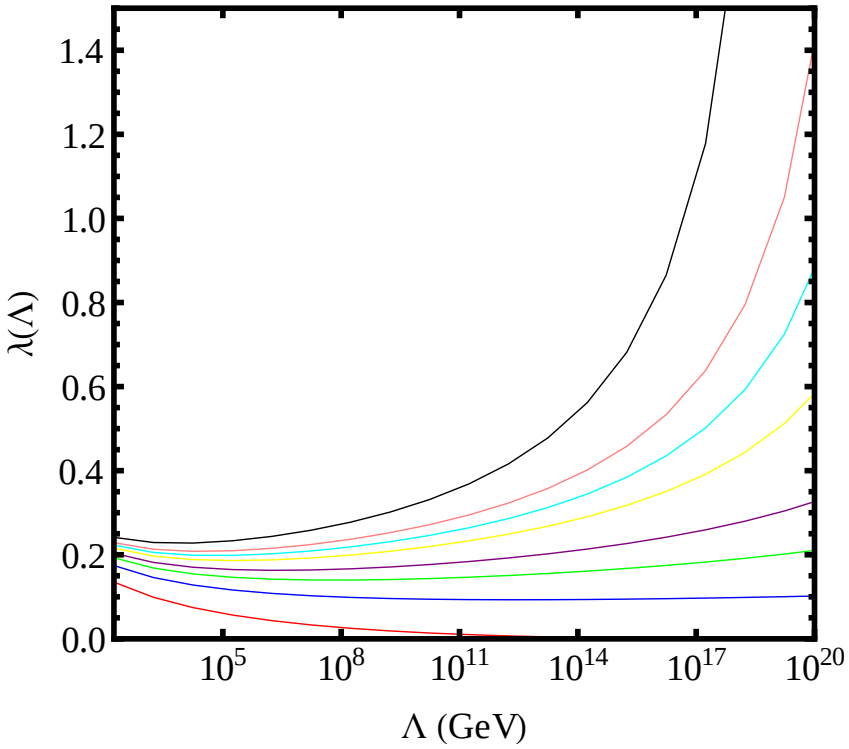
Definition: A theory is **renormalizable á la Wilson** if it possesses a RG fixed point with a finite number of relevant parameters.

Two kinds:

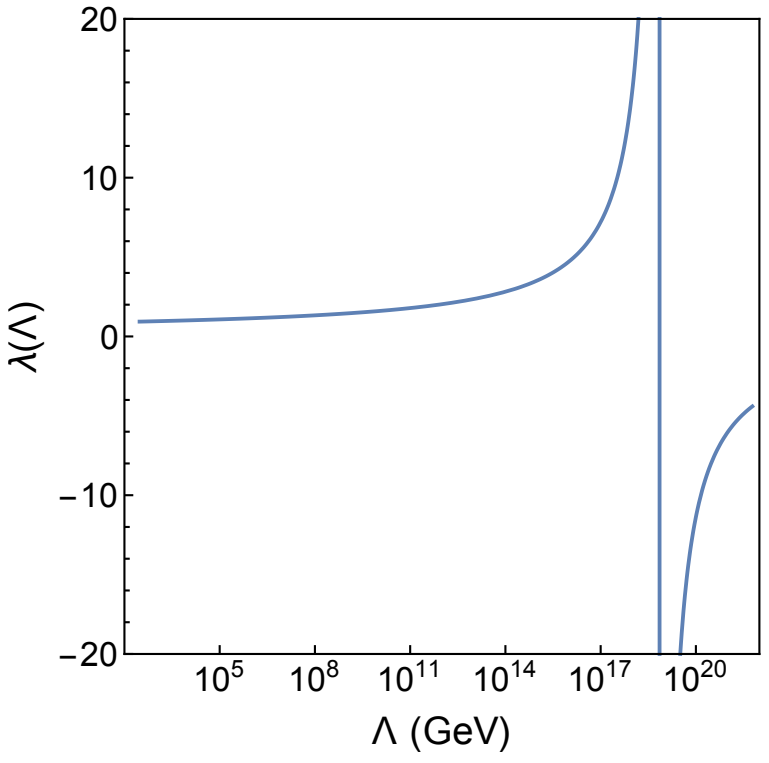
- **Asymptotic Freedom**
  when the fixed point describes a non-interacting theory
- **Asymptotic Safety**
  otherwise

RG Flow in the Standard Model

The SM is perturbatively renormalizable, but not UV complete



(Holthausen, Lim, Lindner '12)



Landau pole

Light Higgs = almost vanishing self-interaction to high scales

RG Flow in the Standard Model

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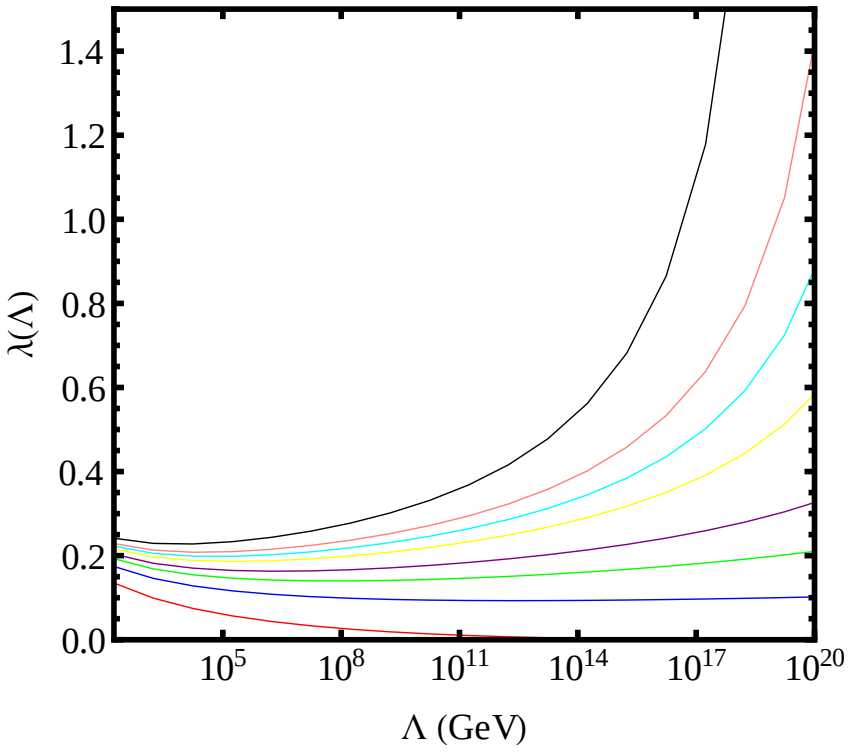

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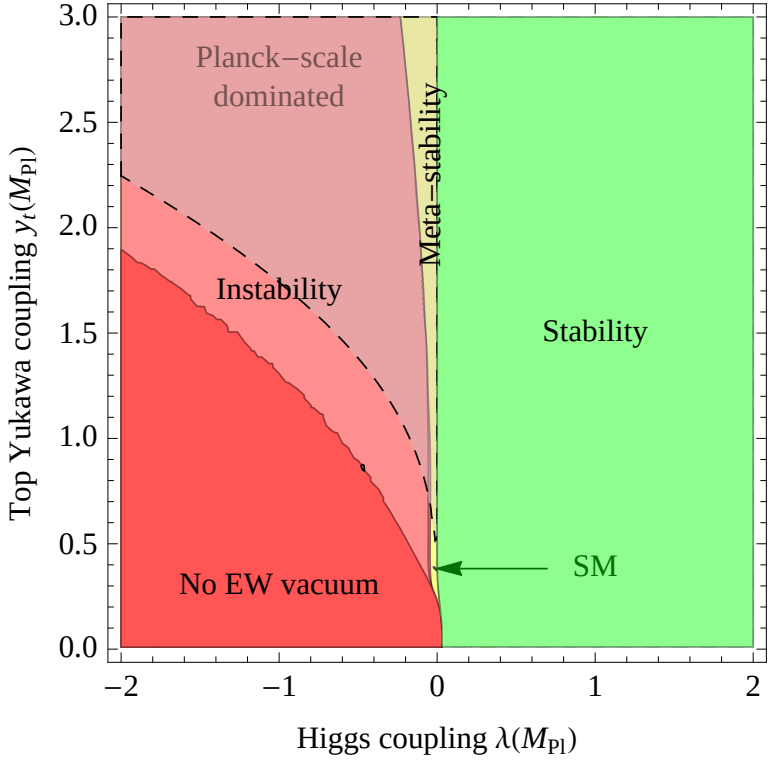


(Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia '13)

Light Higgs = almost vanishing self-interaction to high scales

RG Flow Beyond the Standard Model

Beyond the SM, is **Total Asymptotic Freedom** possible?

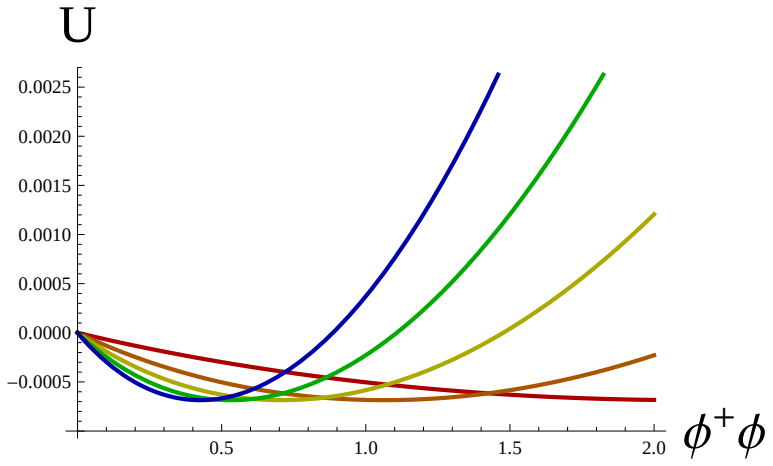
- within perturbative renormalizability: it is rare
  needs many new particles

  (Giudice, Isidori, Salvio, Strumia '15) (Holdom, Ren, Zhang '15)

- beyond perturbative renormalizability: it is common

  ✓ non-Abelian Higgs-Yukawa models (e.g. GUT)

  (Gies, **LZ** '15 & '16) (Gies, Sondenheimer, Ugolotti, **LZ** '18 & '19)



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  ?? SM-like Higgs-Yukawa models (with $U(1)_Y$):

  work in progress: SM + higher-dimensional operators (Gies, Vacca, **LZ**)

  work in progress: SM + hidden sector (Litim, Vacca, **LZ**)

RG Flow Beyond the Standard Model

Beyond the SM, is **Asymptotic Safety** possible?

Several scenarios have been proposed:

- with Quantum Gravity (Reuter et al.) (Percacci et al.) ...
- Large N_f & N_c (Litim, Sannino '14)

  but $U(1)_Y$ needs a cure (Dondi, Dunne, Reichert, Sannino '20)

  work in progress: (Litim, Vacca, **LZ**)
- in Nonlinear Sigma Models (Percacci, Codello '09)

  (Percacci, Fabbrichesi et al. '10 & '11)

  in preparation: (Vacca, **LZ**)

Methodology

Wilsonian Renormalizability sets a stage for a rigorous definition of

Scale Invariance and **Hierarchies of Scales**

but, the question remains **hard!** (nonperturbative)

Needs **methodological innovations**

- Functional methods
- Exact RG Equations

$$\partial_t \Gamma = \frac{1}{2} \left(\Gamma^{(2)} + R \right)^{-1} \partial_t R$$

- Effective Field Theory
- Conformal Field Theory

Methodology

Applications to:

1. SM and BSM gauge hierarchy problem

   in preparation: (Gies, Schmieden, **LZ**)

2. dynamical mass generation in non-Abelian gauge theories

   (Gies, Gkiatas, **LZ** '22)

   in preparation: (Asnafi, Gies, Gkiatas, **LZ**)

3. critical nonlinear sigma models

   (Baldazzi, Percacci, **LZ** '21)

   in preparation: (Vacca, **LZ**)

Conclusions

Still plenty of room for (theoretical) discoveries

Thank you and stay tuned!