Radiatively Induced Fermi Scale and Unification

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CP^3 Origins

Rencontres de Blois
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Phys.Rev. D91 (2015) 9, 095021 (TA, H. Gertov, F. Sannino, K. Tuominen)
Phys.Rev. D92 (2015) 9, 095003 (H. Gertov, A. Meroni, E. Molinaro, F. Sannino)

Outline

I

Introduction

Unification

- Why $\mathrm{SU}(3)_\mathrm{c} \times \mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_Y$?
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Two time-honoured schemes

Georgi–Glashow	Pati–Salam
• Unification of colour and electroweak interactions to e.g. SU(5) or SO(10) • Gauge-mediated proton decay • $\Lambda_{\mathrm{GUT}} \gtrsim 10^{15}$ GeV	• Unification of colour and lepton number to $SU(4)_{LC}$ • No proton decay via gauge interactions • Leptoquarks mediate rare kaon decay $K_L \to \mu^\pm e^\mp$ • $\Lambda_{\mathrm{GUT}} \gtrsim 1.9 \times 10^6$ GeV

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  - $\langle P \rangle \sim \Lambda_{\mathrm{GUT}}$ and $\langle H \rangle = v_w$
- The SM scalar potential: $V_{\mathrm{SM}} = m_H^2 H^\dagger H + \lambda_H (H^\dagger H)^2$
  - Higgs mass 125 GeV $\Rightarrow \lambda_H = 0.13$
  - $m_H^2 = -\lambda_H v_{\mathrm{w}}^2$

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  - $m_H^2 = -\lambda_H v_{\mathrm{w}}^2$
- **But:** SM feels the GUT scalars via portal interaction $\lambda_{\mathrm{mix}} H^\dagger H \,\mathrm{Tr}[P^\dagger P]$
  - $\langle P \rangle$ induces a mass term $\sim \lambda_{\mathrm{mix}} \Lambda_{\mathrm{GUT}}^2$ for H
  - λ_{mix} has to be highly suppressed $(\lambda_{\mathrm{mix}} \lesssim v_{\mathrm{w}}^2/\Lambda_{\mathrm{GUT}}^2)$

    $\Rightarrow$ Huge hierarchy between λ_{mix} and λ_H

Emergent Fermi scale due to vacuum misalignment

- Enlarge the symmetry of the SM scalar sector to G
  - SSB $G \to H$ via a scalar vev $\langle\sigma\rangle$
  - This should also break $\mathrm{SU}(2)_{\mathrm{L}} \times \mathrm{U}(1)_Y \to \mathrm{U}(1)_Q$

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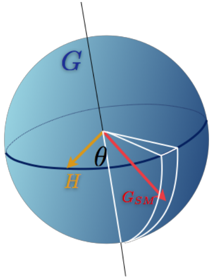
- Embed EW gauge group into G
  - If G large enough, possibility of different embeddings
  - Amount of EW breaking as $G \to H$ depends on the alignment of H wrt EW group
  - If $\sin\theta$ gives the alignment, then $v_{\mathrm{W}} = \sin\theta \langle \sigma \rangle$
  - If $\theta \ll 1$, then $\langle \sigma \rangle \gg v_{\mathrm{W}}$
- Pushes origin of EWSB and new physics to higher scales!



[Figure: A. Meroni]

II

Elementary Goldstone Higgs

$SU(4) \to Sp(4)$ breaking pattern

- The breaking $SU(4) \to Sp(4)$ achieved by a scalar M in $6_A \in SU(4)$
  - Leaves behind 5 GB's, Π_i
  - These decompose as $(2,2)+(1,1)$ under $SU(2)_L \times SU(2)_R$
    $\Rightarrow$ Allows for SM-like Higgs bi-doublet of GB's
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- Different alignments between EW group and Sp(4)
  - GB-like vacuum E_{GB} leaves EW intact
  - Higgs-like vacuum E_H breaks EW$\to U(1)_Q$
  - In general, a superposition of these $E = \cos\theta\, E_{GB} + \sin\theta\, E_H$

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  - In general, a superposition of these $E = \cos\theta\, E_\mathrm{GB} + \sin\theta\, E_H$
- Composite-Higgs scenario of $\mathrm{SU}(4) \to \mathrm{Sp}(4)$ breaking already studied [Cacciapaglia & Sannino 2014]
  - $\mathrm{SU}(2)_\mathrm{TC}$ gauge group with 2 Dirac fermions

Electroweak gauge sector and SM fermions

- Embed $\mathrm{SU}(2)_\mathrm{L} \times \mathrm{SU}(2)_\mathrm{R}$ into SU(4)
  - Gauge the EW symmetry $\Rightarrow$ Breaks SU(4) explicitly
- As M acquires vev, the EW bosons get masses

$$m_W^2 = \frac{1}{4} g^2 v^2 \sin^2\theta, \text{ and } m_Z^2 = \frac{1}{4}(g^2 + g'^2) v^2 \sin^2\theta$$

- Elementary scalars $\Rightarrow$ masses for SM fermions without further dynamics
- For the vacuum analysis, the top quark is dominant
- The top gets mass as M acquires vev, $m_t = \frac{y_t}{\sqrt{2}} v \sin\theta$
- The vacuum angle θ is *a priori* a free parameter

One-loop potential

- The true vacuum is determined by quantum corrections
- Calculate the one-loop Coleman–Weinberg potential
  - $V^{(1)}(\Phi) = \frac{1}{64\pi^2}\mathrm{Str}\left[M^4(\Phi)\left(\log\frac{M^2(\Phi)}{\mu_0^2} - C\right)\right]$
- The EW and top sectors break the global SU(4) symmetry at one-loop level
  - Picks a preferred value for the vacuum angle θ
  - Gives mass to the pseudo-Goldstone boson Π_4

  $\Rightarrow$ pGB Higgs

III

Pati–Salam Unification

Symmetry structure

- Global symmetry of the scalar sector $\mathrm{SU}(4)_\chi$
  $\Rightarrow$ The natural unification scenario is à la Pati–Salam
  - Unify colour with lepton number
    $\Rightarrow \mathrm{SU}(4)_{\mathrm{LC}}$ of leptocolour
    $\Rightarrow$ The full symmetry $G = \mathrm{SU}(4)_\chi \times \mathrm{SU}(4)_{\mathrm{LC}}$
- The simplest realisation to illustrate the idea
  - M breaks $\mathrm{SU}(4)_\chi \to \mathrm{Sp}(4)_\chi$
  - Add another scalar multiplet, P, to break the leptocolour

The scalar potential

- The simplest scalar potential is $V = V_M + V_P + V_{MP}$, where

$$V_M = \frac{1}{2} m_M^2 \mathrm{Tr}[M^\dagger M] + \frac{\lambda_M}{4} \mathrm{Tr}[M^\dagger M]^2,$$

$$V_P = \frac{1}{2} m_P^2 \mathrm{Tr}[P^\dagger P] + \lambda_{P1} \mathrm{Tr}[P^\dagger P]^2 + \lambda_{P2} \mathrm{Tr}[P^\dagger P P^\dagger P],$$

$$V_{MP} = \frac{\lambda_{MP}}{4} \mathrm{Tr}[M^\dagger M] \mathrm{Tr}[P^\dagger P]$$

Results

- Fix $\Lambda_{\mathrm{GUT}} = \langle P \rangle = 2.5 \cdot 10^6$ GeV (above the experimental bound)
- Is it possible to find parameters that
  1. give the correct EW spectrum ($v \sin\theta = v_{\mathrm{w}}$)
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- Is it possible to find parameters that
  1. give the correct EW spectrum ($v \sin\theta = v_{\mathrm{w}}$)
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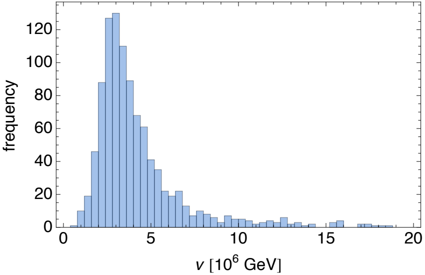
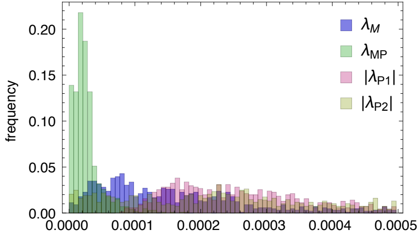
- Yes!
  - Typically $v \sim \Lambda_{\mathrm{GUT}}$
  - All quartic coupings are small ($\lesssim 0.01$) **but** no large hierarchy between them
  - The mass parameters of the same order





Conclusions and Outlook

- Vast hierarchy between the Fermi and the unification scale
- No hierarchy problem if the Fermi scale generated radiatively
  - Extended global symmetry & vacuum misalignment $\Rightarrow v_w = v \sin\theta$
  - If $\theta \ll 1$, possible that $v \sim \Lambda_{\mathrm{GUT}}$
- Viable realisation within the Pati–Salam framework
  - Quartic scalar couplings small, but of the same order

Possible further avenues:

- What about Georgi–Glashow GUTs?
- Dark Matter
  - One more EW-singlet GB $\Rightarrow$ DM candidate
- Inflation
  - $\lambda_i \ll 1 \Rightarrow$ Higgs inflation with $\xi = \mathcal{O}(1)$ non-minimal coupling?

Thank you!