Conformal Standard Model

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  – Hierarchy problem: quantum corrections to the only dimensionful parameter give $m^2 \sim \Lambda^2 \Rightarrow$ why $m \ll M_{Pl}$?

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  – no candidate for CDM
- – why 3 generations?
  (is it significant that the number of fermions, 48, and their electric charge assignments are the same as in $N = 8$ gauged supergravity with $SU(3) \times U(1)$?)

K.A.M., H. Nicolai, Phys.Rev. D91 (2015) 065029

Extending SM
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- see-saw mechanism for neutrinos,
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- there is a candidate for CDM,
  observed baryon/photon ratio possible

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- $\mathcal{L} = \mathcal{L}_{kin} + \mathcal{L}'$:

$$\begin{aligned}\mathcal{L}' \;=\; & \Big(\bar{L}^i \Phi Y^E_{ij} E^j + \bar{Q}^i \epsilon \Phi^* Y^D_{ij} D^j + \bar{Q}^i \epsilon \Phi^* Y^U_{ij} U^j + \\ & + \bar{L}^i \epsilon \Phi^* Y^\nu_{ij} N^j + y_M \varphi_{ij} N^{iT} \mathcal{C} N^j + \text{h.c.}\Big) \\ & - m^2_\Phi (\Phi^\dagger \Phi) - m^2_\phi \text{Tr}(\varphi \varphi^\star) \\ & - \lambda_1 (\Phi^\dagger \Phi)^2 - 2\lambda_3 \text{Tr}(\varphi\varphi^\star)(\Phi^\dagger\Phi) - \lambda_2 \left(\text{Tr}(\varphi\varphi^\star)\right)^2 \\ & - \lambda_4 \text{Tr}(\varphi\varphi^\star\varphi\varphi^\star)\end{aligned}$$

complex fields $\phi = \phi_{ij} = \phi_{ji}$, $i, j = 1, 2, 3$, charge$_L = -2$,
$m_\Phi, \; m_\phi \sim 1$ TeV

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  SSB of the lepton number symmetry
  $\langle\varphi_{ij}\rangle = v_\phi \delta_{ij} \neq 0$
- see-saw mechanism for neutrinos:

$$y_M \sim O(1), \quad Y_{ij}^\nu \sim O(10^{-6}), \quad m_\nu \sim \frac{v^2}{v_\phi}\frac{Y_\nu^2}{y_M} \ll 1\,\mathrm{eV}$$

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  - phases of new scalar field very light and extremely weakly coupled – candidates for DM

Hierarchy problem

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- we treat the cutoff scale Λ ($\sim M_{Pl}$) as a bona fide physical scale and we define all 'bare' quantities at Λ

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- vanishing of quadratic divergences is imposed on 'bare' parameters (at scale Λ)

$$f_H(\Lambda) = \frac{9}{4}g_w^2 + \frac{3}{4}g_y^2 + 6\lambda_1 + 12\lambda_3 - 6y_t^2 \,!= 0$$

$$f_\phi(\Lambda) = 14\lambda_2 + 4\lambda_3 + 8\lambda_4 - |y_M|^2 \,!= 0$$

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- at some smaller scale Λ_1 the RHS $\neq 0$

$$f_H(\Lambda_1) = C_H(\Lambda, \Lambda_1), \quad f_\phi(\Lambda_1) = C_\phi(\Lambda, \Lambda_1)$$

but $C_i = f_i(\Lambda_1) - f_i(\Lambda)$ i.e. the same conditions.

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- it turns out that it decouples at low energies into (conformally non-invariant) gravity and (conformally invariant) $N = 4$ SYM theory
- we conjecture that such a decoupling of gravity and particle sectors below the Planck scale is a general phenomenon allowing for 'soft breaking' of conformal symmetry

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  good candidates for CDM

Phenomenology – examples

$\lvert y_M \rvert$	M_N	$M_{h'}$	M_R	$\tan\beta$	$\Gamma_{h'}$	$h' \to SM$	$h_0 \to SM$
0.56	545	378	424	-0.3	3.1	0.59	0.69
0.54	520	378	360	-0.3	3.1	0.59	0.68
0.75	1341	511	1550	0.25	6.2	0.73	0.91
0.75	2732	658	3170	-0.16	5.9	0.74	0.99
0.82	2500	834	2925	0.15	10.9	0.74	0.98

(dimensionful parameters in GeV)
125 GeV mass eigenstate assumed, equations for vanishing quadratic divergences satisfied, $\lvert\tan\beta\rvert \leqslant 0.3$

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- CSM has only several more parameters than SM (MSSM 116)
- CSM vacuum stable up to M_{Pl}
  all coupling constants small up to M_{Pl}
- baryogenesis through resonant leptogenesis can accommodate baryon/photon ratio $\eta \sim 10^{-10}$ observed in our Universe

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- other scalars and right-chiral neutrinos (masses $\sim$ 1 TeV) too weakly coupled to SM particles to be visible in LHC
- extremely light and naturally weakly coupled phases – CDM candidates
- time will tell whether the predicted scalar particle will be seen by the LHC...