Field Bifurcations and the Challenges of the Higgs Sector

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Abstract

The Higgs mechanism of electroweak symmetry breaking (EWSB) has several conceptual challenges that are currently unresolved. We recently put forward an alternative embodiment of EWSB based on sequential field bifurcations driven by the Renormalization scale. This brief report points out that the bifurcation scenario can evade three shortcomings of the standard EWSB, related to the gauge hierarchy problem, triviality, and the tachyonic mass term.

Key words: Higgs mechanism, electroweak symmetry breaking, gauge hierarchy problem, Higgs triviality, tachyonic mass term, Feigenbaum route to chaos, period-doubling bifurcations.

The standard Higgs model of EWSB is based on the fundamental scalar doublet

$$\varphi = \begin{pmatrix} \varphi^{+} \\ \varphi^{0} \end{pmatrix} \tag{1}$$

acted upon the double-well potential

$$V(\varphi) = \lambda(\varphi^{+}\varphi - \frac{\mathrm{v}^2}{2})^2 \tag{2}$$

Although the framework described by (1) and (2) is fully renormalizable and consistent with experimental data, there are few nagging puzzles that remain open to date. In particular [1-2],

1) In the absence of physics beyond the Standard Model, quantum corrections to the Higgs mass are on the same order of magnitude with the ultraviolet cutoff of the theory, $m_H^2 \propto \Lambda_{UV}^2$. It follows that the electroweak scale is necessarily unstable, an issue leading to the *gauge hierarchy problem*.

2) Taking the continuum limit $\Lambda_{UV} \to \infty$ leads to a theory that is free or trivial as the Higgs self-coupling vanishes away ($\lambda \to 0$). The *triviality* of the standard Higgs scenario implies that the standard EWSB model is (at best) an effective low-energy approximation, bound to fail below some cutoff scale $\Lambda \leq \Lambda_{UV}$.

3) An often-cited criticism of the EWSB model is that the form of the potential (2) is not determined from first principles, but it is rather put in "by hand". The issue is alternatively phrased as the *tachyonic mass* problem because symmetry breaking in (2) is enabled by the negative sign of the Higgs mass term, $\mu_H^2 = -\lambda \mathrm{v}^2 < 0$.

It was conjectured in [3-4] that the Standard Model gauge group unfolds under progressive bifurcations of the Higgs potential. The flow of the Higgs potential with the Renormalization scale μ reduces to the cubic map

$$\dot{y} = my(1 - y^2) \tag{3}$$

in which y and $\dot{y}$ are given by

$$y = \frac{\sqrt{2}}{\mathrm{v}}\varphi \tag{4}$$

$$\dot{y} = \frac{dy}{d(\log \mu/\mu_0)} \tag{5}$$

Here, φ denotes the amplitude of the complex-scalar field whose vacuum expectation value is $\mathrm{v} = 246$ GeV. The control parameter of (3) contains the self-coupling λ and an arbitrary reference scale m_0 as in

$$m = \frac{2\lambda \mathrm{v}^2}{m_0^2} \tag{6}$$

With reference to Fig. 1, the first instability of (3) occurs at $m=1$, which sets the Higgs mass at the EWSB value, namely

$$m_H^2 = 2\lambda \mathrm{v}^2 \tag{7}$$

We argue next that the above-mentioned challenges can be evaded in the context of this bifurcation model. The arguments go as follows:

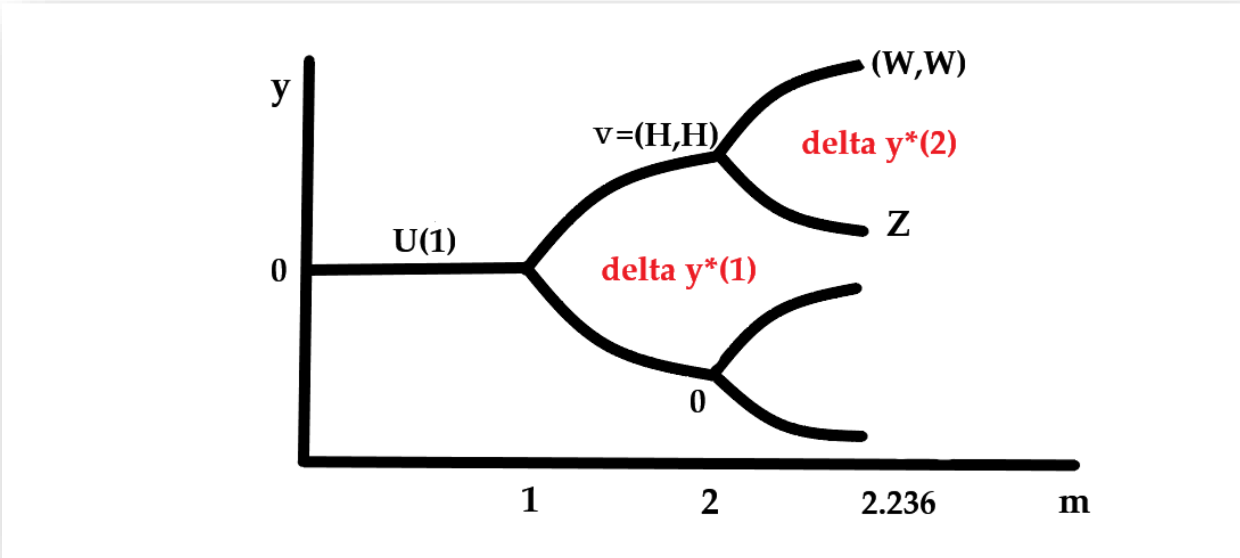

Fig. 1: Bifurcation diagram of EWSB

1A) The hierarchy problem goes away as the Higgs condensate *does not survive* past the second bifurcation vertex V_2, at which point it successively bifurcates and morphs into the entire flavor structure of the Standard Model.

2A) A key feature of a spacetime manifold endowed with minimal fractality (called a *minimal fractal manifold*, or the MFM) is that the continuous deviation from four space dimensions runs with the Renormalization scale μ and takes the form [5]

$$\varepsilon(\mu) = 4 - D(\mu) = O[\frac{m^2(\mu)}{\Lambda_{UV}^2}] << 1 \quad (8)$$

Dimensional deviation (8) may be thought about as an *intrinsic polarization* of the MFM, which generates both particle masses and interaction strengths. In this context, a reasonable assumption is that λ scales in some linear fashion with (8),

$$\lambda(\mu) \propto \varepsilon(\mu) \quad (9)$$

(9) provides a natural motivation for the triviality problem, as $\lambda \to 0$ when $\Lambda_{UV} \to \infty$.

3A) It can be argued that the Landau-Ginzburg potential (2) is not arbitrary but follows from the physics of far-from-equilibrium systems and self-organization [6-7]. From this vantage point, the tachyonic mass problem appears to be rooted in the *nonlinear dynamics of complex systems*. This conclusion is supported by the fact that the Higgs mass (7) emerges from the instability of the cubic map (3) at the first bifurcation vertex V_1.

References

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