December 31, 2025

Farewell to the parameter zoo: bilan 2025

100 years after Heisenberg: from matrices to octonions

Key Insight. Looking back, many seemingly independent parameters of particle physics (couplings, scales, mass ratios, mixing angles) can be traced back to a small set of octonionic and Albert-algebra structures: octaves, G_2 and F_4, heptagon and radius operators, rotors and compressors, and the vacuum configuration $\langle H \rangle$. One hundred years after Heisenberg's matrix mechanics, the algebraic heritage of quantum theory is alive and extended: from noncommutative matrices to nonassociative octonions. At the dynamical level, this heritage takes the form of a single master action $S[D, \Psi]$ whose few coefficients and algebraic invariants replace the many ad hoc parameters of the Standard Model.

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From a zoo of inputs to a structured atlas

The Standard Model appears to need dozens of free parameters: gauge couplings, Yukawas, mixing angles, mass ratios, vacuum expectation values, hierarchy scales. Over the course of this Advent calendar, many of them have been reinterpreted as:

- invariants of the F_4 symmetry atlas on $H_3(\mathbb{O})$,
- eigenvalues of internal operators (H_7, R, compressors),
- equilibrium values of internal potentials (e.g. Y_S),
- spectral data of a Dirac operator on a structured vacuum.

What looked like a parameter zoo is largely a shadow of one coherent geometric structure.

The algebraic backbone

The backbone of the model consists of:

- **Number system:** octonions $\mathbb{O}$ and their automorphism group G_2.
- **Symmetry atlas:** the Albert algebra $H_3(\mathbb{O})$ and its automorphism group F_4.
- **Operators:** heptagon operator H_7, radius operator R, rotors and compressors.
- **Vacuum:** a distinguished configuration $\langle H \rangle$ and associated scales (a_0, b_0, c_0), Y_S.

From this small list, one can systematically derive:

- the existence of three generations (triality),
- the pattern of gauge couplings (via rotor norms),
- the presence of three main scales (via $\mathrm{spec}(R)$),
- the structure of mass matrices and mixings (via compressors and $\Pi(\langle H \rangle)$),
- candidates for dark sectors and vacuum energy contributions.

From many parameters to one action

In a conventional presentation, the Standard Model Lagrangian carries a long list of independent couplings, masses and mixing parameters. In the octonionic formulation used in this project, the dynamics is organised by a single master action

$$S[D, \Psi] = \int_{M_4} \sqrt{-g} \Big(\mathcal{L}_{\mathrm{kin}}[D] + \mathcal{L}_F[D] + \mathcal{L}_G[D] + \mathcal{L}_{\mathrm{Defekt}}[D] + \mathcal{L}_{\mathrm{matter}}[$$

where D encodes spin connection, gauge fields and compressor/Yukawa blocks, and Ψ collects three generations of fermions.

Most of the "parameters" then become:

- discrete choices of vacuum data $(\langle H \rangle; a_0, b_0, c_0; Y_S)$,
- algebraic invariants of the F_4 symmetry atlas,
- and a small set of dimensionless coefficients in front of the operator blocks in $S[D, \Psi]$.

The parameter zoo is not abolished, but it is *relocated*: from many unrelated input numbers to a handful of structural choices in the exceptional master action.

Open block: gravity

Not everything is solved. A central open question remains:

$$\kappa = \frac{m_p}{m_P},$$

the ratio of proton mass to Planck mass. Together with the cosmological scale Λ, it marks the gravitational block that has not yet been fully integrated into the octonionic sector.

The spectral-action approach suggests a path:

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$$S_{\text{spec}} = \mathrm{Tr}\, f(D^2/\Lambda^2),$$

where D encodes both space-time and internal octonionic geometry. In a future project, this may allow κ and Λ to be understood as spectral invariants, closing the remaining gap —in other words, to derive the remaining gravitational coefficients in $S[D, \Psi]$ from the same spectral data that govern the internal sector.

A century after Heisenberg

In 1925, Heisenberg introduced matrix mechanics, marking the beginning of quantum theory as an algebraic theory of observables. One hundred years later, the present model can be read as a continuation of that line of thought:

- from matrices to nonassociative algebras,
- from $SU(2)$ to G_2 and F_4,
- from a list of parameters to a structured atlas of invariants.

The core lesson is not that octonions are "exotic", but that algebraic structure remains a powerful guide for understanding physical reality.

From fitting to understanding

The transition can be summarised in one sentence:

> We move from *fitting* independent constants to *understanding* them as coordinates on orbits in an exceptional symmetry atlas.

This is not the final word—open questions remain, especially on gravity and cosmology—but it marks a coherent step towards a less fragmented picture of fundamental physics.

The reduction of the parameter zoo is thus conceptual and structural rather than yet numerically complete: many patterns are explained, but precise values and quantum corrections remain an open and testable part of the programme.

References

[1] W. Heisenberg, "Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen," *Z. Phys.* **33**, 879–893 (1925).

[2] P. A. M. Dirac, "The cosmological constants," *Nature* **139**, 323 (1937).

Many "free parameters" of particle physics become invariants of an exceptional symmetry atlas built from octonions and the Albert algebra. One hundred years after Heisenberg, the algebraic spirit of quantum mechanics extends from matrices to nonassociative structures, pointing towards a less fragmented understanding of constants and scales.

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