Personal and professional anamneses from my collaboration with Costas Kounnas

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Working with Costas Kounnas

Costas Kounnas scientific work extends over many areas of Theoretical Physics. Although, I knew him for a long time, I can't really say which field he liked most.

However, what I can definitely say is that whenever he focused on a particular problem with his collaborators, very soon that field turned out to be his favourite field.

I had the privilege of collaborating with him in one of his favourite research fields that was "String Phenomenology".

String model building

Back in 2003, when I was visiting ENS, Costas was interested in a new systematic approach to string model building. His favourite framework was the "Free Fermionic Formulation" a method developed by I. Antoniadis, C. Bachas and C. Kounnas, that allows the direct construction of string models in 4D.

In the Free Fermionic Formulation a string model is defined by a set of n basis vectors $\beta_1, \ldots, \beta_n$ which encode the boundary conditions of the world-sheet fermions, and a set of phases $c\begin{bmatrix}\beta_i\\\beta_j\end{bmatrix}$ associated with generalised GSO projections.

Several phenomenological interesting models were constructed in this framework, what was lacking at that time was a systematic approach and classification of the plethora of candidate 4D vacua. However, this was almost an impossible, even with the help of a computer, as a typical model comprised $n \sim 10$ basis vectors and a number of $n(n-1)/2 \sim 45$ undetermined GSO phases leading to $\sim 10^{14}$ models.

String model building

After, endless discussions with Costas Kounnas and Alon Faraggi we ended up in finding a solution by restricting to a fixed basis set that defines a general $SO(10)$ embedding and considering the generalised GSO phases as parameters. An additional basis vector was utilised to break $SO(10)$ down to some of its subgroups (Pati–Salam, Flipped $SU(5)$, $MSSM$, etc). In this context, we were able to derive analytic formulae describing the main phenomenological characteristics of each model in terms of the generalised GSO phases.

String model building

This method, which has since been adopted in the classification of fermionic models, has allowed the systematic computer-assisted scanning of huge classes of models. It has also led to some interesting results that include:

- An interesting property of the spectra of these vacua termed spinor-vector duality. This property was utilised later in the construction of models with an extra anomaly free $U(1)$ that could survive down to low energies.
- The discovery of Pati–Salam models free of fractional charge exotics.

Recently, in collaboration with S. Abel and L. Nutricati we have succeeded in implementing this method on a Quantum Annealer.

Non-supersymmetric models

As has been known since the early days of the first superstring revolution, besides the space-time supersymmetric $\mathrm{E}_8 \times \mathrm{E}_8/\mathrm{SO}(32)$ heterotic string theory one can construct consistent non-supersymmetric theories as the $\mathrm{SO}(16) \times \mathrm{SO}(16)$ heterotic string model.

A coordinate dependent compactification corresponding to a stringy realization of the Scherk–Schwarz mechanism can be used to obtain spontaneous breaking of supersymmetry.

In general, these models feature a cosmological constant. At the limit of large compactification radius R the one-loop effective potential can be recast in the form

$$V_{\text{eff}} = -\frac{\zeta}{R^4} + \mathcal{O}\left(e^{-\lambda R}\right) \ ,$$

where ζ is a constant associated with massless spectrum degeneracies and λ is a positive constant of order one.

Super no-scale models

Costas was fascinated by these models and he had spent a lot of time studying them. In particularly he focused on a subclass of these models where the cosmological constant was exponentially suppressed

$$\zeta \sim n_B - n_F \,,$$

a subclass he termed as “super no-scale models”.

He constantly urged us to build explicit examples of such models. A few years ago he was very happy to hear that in collaboration with his student I. Florakis we succeeded in constructing concrete examples of 4D “super no-scale” models.

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