PhD thesis proposal – 2022-2025

Research field: Theoretical Physics

Thesis title: Non-perturbative Aspects of Supersymmetric Field Theories from String Dualities
('Aspects non-perturbatifs des théories quantiques des champs supersymétriques à partir des dualités en théorie des cordes')

Supervisor: Stefan HOHENEGGER

Phone: +33 4 72 44 84 34

Email: s.hohenegger@ipnl.in2p3.fr

Address: IP2I Lyon – Bureau 339
Domaine Scientifique de la Doua – Bât. Paul Dirac
4 rue Enrico Fermi – 69622 Villeurbanne Cedex - France

Work description:

Our current understanding of most of the interactions of elementary particles relies strongly on perturbative methods in quantum field theories (QFTs): calculations are organised in powers of a small parameter (typically the coupling constant that is related to the strength of the interaction among elementary particles) and truncated after a certain order. Such methods therefore work very well in the weak-coupling regime, where this truncation is well justified, and over the years impressive computational methods have been developed. Going beyond the weak-coupling regime is both technically and conceptually very difficult, but may be necessary, since there may exist symmetries and structures that are inherently of a non-perturbative nature (and thus invisible in an order-by-order expansion in the coupling).

The basic idea of this project is to exploit the technical progress that has been made in developing perturbative methods in order to compute intrinsically non-perturbative quantities. The starting point is a recent observation [1, 2] that allows to decompose part of the non- perturbative free energy of a particular class of QFTs in terms of simple building blocks that can be computed very efficiently using perturbative methods. These theories are so-called supersymmetric QFTs, which possess an additional symmetry that relates fermionic particles (which are the basic building blocks of matter) to bosonic particles (which are responsible for the transmission of forces between matter). While such a symmetry is not found at the energy scale of current collider experiments, it provides additional structure, which simplifies enormously many of the computations. Supersymmetric theories are therefore a very useful testing ground for new ideas and methods, which may then be extended to more realistic theories.

Concretely, the particular theories considered in this project can be obtained from string theory (or some of its higher dimensional avatars, such as M-theory or F-theory) by means of various different constructions. Indeed, these conceptually very different approaches furnish complementary ways of studying these theories and in particular provide numerous calculational tools that allow us to probe even their non-perturbative aspects. Moreover, their intrinsic relation to string theory induces non-trivial dualities among distinct theories of this type which differ in their gauge and matter-content [4]. As demonstrated in [5], these in turn lead to surprising symmetries for individual such theories, which are intrinsically non-perturbative in nature. Finally, these symmetries also provide an organisational principle for the spectrum of the QFTs, which has lead to the above mentioned decomposition of the fully non-perturbative free energy [1, 2] in terms of building blocks that resemble a Feynman diagrammatic expansion.

The concrete goals of the project are threefold:

- Understand abstractly the mechanisms behind the decomposition of the free energy in connection with the symmetries of the underlying QFTs. This task may be guided byinsights from various branches of mathematics, such as geometry, number theory or group theory.
- Extend the decomposition to a larger class of theories with a more general matter content. The class of theories studied in the literature so far can be extended through various deformations or geometric generalisations. Preliminary results indicate that they also enjoy an organisational principle of their spectrum that leads to a similar decomposition of the non-perturbative free energy.
- Explore the possibilities to apply similar techniques in realistic models. Concretely, in- vestigate the possibility to break supersymmetry in a controlled manner, which does not destroy the organisational principle of the spectrum of the theory, thus not spoiling the decomposition of the free energy.

References

[1] S. Hohenegger, From Little String Free Energies Towards Modular Graph Functions, JHEP 03 (2020), 077 doi:10.1007/JHEP03(2020)077 [arXiv:1911.08172 [hep-th]].

[2] S. Hohenegger, Diagrammatic Expansion of Non-Perturbative Little String Free Energies, JHEP 04 (2021), 275 doi:10.1007/JHEP04(2021)275 [arXiv:2011.06323 [hep-th]].

[3] S. Hohenegger and A. Iqbal, M-strings, elliptic genera and N = 4 string amplitudes, Fortsch. Phys. 62 (2014), 155-206 doi:10.1002/prop.201300035 [arXiv:1310.1325 [hep-th]].

[4] B. Bastian, S. Hohenegger, A. Iqbal and S. J. Rey, Triality in Little String Theories, Phys. Rev. D 97 (2018) no.4, 046004 doi:10.1103/PhysRevD.97.046004 [arXiv:1711.07921 [hep-th]].

[5] B. Bastian and S. Hohenegger, Dihedral Symmetries of Gauge Theories from Dual Calabi- Yau Threefolds, Phys. Rev. D 99 (2019) no.6, 066013 doi:10.1103/PhysRevD.99.066013 [arXiv:1811.03387 [hep-th]].