PREFACE

Quantum integrable models and gauge-string duality

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PREFACE

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Remarkable progress has been achieved in the last 10 years in the quantitative understanding of gauge/string duality. For the first time it now appears that it will be possible to find the exact solution of a 4-dimensional interacting quantum field theory. This should have important implications for our understanding of other strongly coupled gauge theories such as Quantum Chromodynamics.

The most studied is the most symmetric example of a gauge-string duality—the correspondence between the maximally supersymmetric gauge theory in flat 4 dimensions and superstring theory in a curved space $AdS_5 \times S^5$, also refered to as AdS/CFT duality. The solvability of this model, allowing us for example to compute the dimensions of gauge invariant operators for any value of the coupling, is due to its hidden integrability. At weak coupling this integrability is seen by identifying the dilatation operator which acts on single trace operators in the gauge theory with the Hamiltonian of an integrable 1-dimensional spin chain. At strong coupling, where the operators of the gauge theory are most easily identifiable as string states, integrability is manifested by the underlying integrability of the sigma model defined on the string world sheet. As a result, the exact quantum spectrum is determined by a set of thermodynamic Bethe Ansatz equations.

These remarkable developments are based on a wide range of techniques from quantum field theory, condensed matter theory and mathematical physics and were reviewed in a special issue published two years ago:
Kristjansen C, Staudacher M and Tseytlin A (ed) 2009 Integrability and the AdS/CFT correspondence *J. Phys. A: Math. Theor.* **42** 250301

The present special issue is an update: it contains three long reviews by Didina Serban, Benoit Vicedo and Dmytro Volin that cover recent developments and also present a few particular directions in a detailed pedagogical manner.

It starts with a review by Serban [1], where the integrabilitity of the maximally supersymmetric AdS/CFT duality is described systematically starting from the perturbative gauge theory perspective. The spin chain Hamiltonian interpretation of the dilatation operator plays a key role and predictions of the associated asymptotic Bethe ansatz are compared in detail with perturbative string theory predictions at strong coupling. There is also a discussion of very recent developments related to a Thermodynamic Bethe Ansatz (TBA) proposal describing dimensions of operators of finite length, or energies of the corresponding quantum string states.

The second review by Vicedo [2] gives a detailed account of the mathematical formalism underlying the integrability of the classical string sigma model on symmetric curved spaces like $AdS_5 \times S^5$. It first describes the construction of the classical string solution using the finite gap method, leading to an algebraic curve description of solutions. It then introduces a semiclassical WKB-type quantization of string solitonic solutions which determines the leading quantum corrections to the classical string energies, using the example of bosonic strings on $R \times S^3$ as a model. Further extensions and elaborations of these methods for the full $AdS_5 \times S^5$ superstring sigma model will be important for further tests of the TBA-type ansatz for the exact quantum string spectrum.

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The final review, by Volin [3], gives a detailed exposition of several topics in the theory of quantum integrable models such as spin chains and various 1+1 dimensional quantum field theories. The main focus is on functional and integral equations originating from the underlying Bethe ansatz in the thermodynamic limit, which are applied in particular to the study of the strong coupling expansion in the context of AdS/CFT.

We should stress that the methods described in this special issue can be applied to areas beyond the spectral problem in AdS/CFT duality. Scattering amplitudes in gauge theories have been studied extensively over the last few years and will be the subject of a future special issue. Recently, it has been shown that these amplitudes have a hidden integrability and one can imagine using the techniques described in this special issue to study the properties of these amplitudes. These methods may also find use in condensed matter systems, such as the Hubbard model, open string chains, or supergroup chains. They could be applied to some other field theories, as we have already started to see for certain Chern–Simons theories.

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Guest Editors

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