Preface

The 76th session of the Les Houches Summer School in Theoretical Physics was devoted to recent developments in string theory, gauge theories and quantum gravity.

As frequently stated, Superstring Theory is the leading candidate for a unified theory of all fundamental physical forces and elementary particles. This claim, and the wish to reconcile general relativity and quantum mechanics, have provided the main impetus for the development of the theory over the past two decades. More recently the discovery of dualities, and of important new tools such as D-branes, has greatly reinforced this point of view. On the one hand there is now good reason to believe that the underlying theory is unique. On the other hand, we have for the first time working (though unrealistic) microscopic models of black hole mechanics. Furthermore, these recent developments have lead to new ideas about compactification and the emergence of low-energy physics.

While pursuing the goal of unification we have also witnessed a dramatic return to the "historic origins" of string theory as a dual model for meson physics. Indeed, the study of stringy black branes has uncovered a surprising relation between string theory and large-N gauge dynamics. This was cristallized in the AdS/CFT correspondence, which has revived the old hope for a string description of the strong interaction. The AdS/CFT correspondence is moreover a prime illustration of the central role of string theory in modern theoretical physics. Much like quantum field theory in the past, it provides a fertile springboard for new tools, concepts and insights, which should have ramifications in wider areas of physics and mathematics.

The main lectures of the Les Houches school covered most of the recent developments, in a distilled and pedagogical fashion. Students were expected to have a good knowledge of quantum field theory, and of basic string theory at the level, for instance, of the first ten chapters of Green, Schwarz and Witten. The emphasis was on acquiring a working knowledge of advanced string theory in its present form, and on critically assessing open problems and future directions.

The lectures by Bernard de Wit were a comprehensive introduction to supergravities in different dimensions and with various numbers of supersymmetries. Topics covered include the allowed low-energy couplings, duality symmetries, compactifications and supersymmetry in curved backgrounds.

Part of this is older material not easily accessible in the literature, and presented here from a modern perspective.

Eliezer Rabinovici lectured on supersymmetric gauge theories, reviewing earlier and more recent results for $N = 1$, 2 and 4 supersymmetries in four dimensions. These results include the structure of the effective lagrangians, non-renormalization theorems, dualities, the celebrated Seiberg-Witten solution and brane engineering of effective gauge theories.

M-theory and string dualities were introduced in the lectures by Ashoke Sen. He reviewed the conjectured relations between the five perturbative string theories, the maximal $N = 1$ supergravity in eleven dimensions and their compactifications. He summarized our present-day knowledge of the still elusive fundamental or "M theory", from which the above theories derive as special limits. More recent topics include non-BPS branes, where duality is of limited (but not zero) use.

Philip Candelas gave a pedagogical introduction to the important subject of Calabi Yau compactifications. He first reviewed the older material, and then discussed more recent aspects, including second quantized mirror symmetry, conifold transitions and some intriguing relations to number theory. Unfortunately a written version of his lectures could not be included in this volume.

The holographic gauge/string theory correspondence was the subject of the lectures by Juan Maldacena and by Igor Klebanov. Maldacena introduced the conjectured equivalence between string theory in the near-horizon geometries of various black branes and gauge theories in the large $N_{\rm color}$ limit. He focused on the celebrated example of $N = 4$ four-dimensional super Yang Mills dual to string theory in $AdS_5 \times S_5$, and gave a critical review of the existing evidence for this correspondence. He also discussed analogous conjectures in other spacetime dimensions, in particular those relevant to the study of stringy black holes, and of the still elusive little string theory.

Igor Klebanov then concentrated on this duality in the phenomenologically more interesting contexts of certain $N = 1$ and 2 supersymmetric gauge theories in four dimensions. He reviewed the relevant geometries on the supergravity side, which include non-trivial fluxes and fractional branes, and discussed the gravity duals of renormalization group flow, confinement and chiral symmetry breaking. These results have revived and made sharper the old ideas about the "master field" of large N gauge theory.

The lectures of Michael Green dealt with some finer aspects of string dualities and of the gauge theory/string theory correspondence. He discussed higher derivative couplings in effective supergravity actions, focusing in particular on the contributions of instantons both in string theory and on the

Yang Mills side. His lectures also included some introductory material on D-branes. Unfortunately a written version of his lectures could not be included in this volume.

Andrew Strominger gave a detailed introduction to quantum gravity in a de Sitter spacetime. He discussed in particular whether ideas of holography, that have worked well in anti de Sitter, could also be applied in this case. This was one of the more speculative subjects in the school, but a fascinating one not the least because astrophysical observations seem to indicate that we actually live in an accelerating universe.

Finally Michael Douglas gave three lectures on D-brane geometry, and in particular on the problem of classifying all $N = 1$ string-theory vacua, while Alexander Gorsky discussed $N = 1$ and $N = 2$ supersymmetric gauge theories and their relation to integrable models. Nikita Nekrasov lectured on open strings and non-commutative gauge theories.

Some more advanced and/or topical subjects were covered in the accompanying series of seminars. Seminar speakers included Laurent Baulieu, Mirjam Cvetič, Frank Ferrari, Dan Freedman, Bernard Julia, Peter Mayr, Soo-Jong Rey, Augusto Sagnotti, Samson Shatashvili, and one of the organizers (C.B.). There was also a lively weekly student seminar and discussion sessions, which contributed greatly to the lively and stimulating atmosphere of the school. Some of the seminar speakers have kindly accepted to contribute to the present volume.

In the year that has elapsed since the end of the school there have been further developments in the subject. The pp-waves, which arise as Penrose limits of near-horizon geometries, offer for instance a new line of attack on the important problem of solving string theory in Ramond-Ramond backgrounds. Such developments and others will no doubt make, one day, the present volume obsolete. This is of course no reason for regret – to the contrary we hope that this may happen sooner rather than later, and that the participants of this school will help shape the (non-recognisable?) future form of M theory.

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- the board of the School and in particular François David, who has worked tirelessly at all different stages (funding applications, admissions, running the session, preparation of proceedings) exceeding often the organizers in zeal and energy;

- the secretaries Mmes G. D'Henry, I. Lelièvre and B. Rousset (and the other personnel of the school), who helped solve administrative and everyday problems;
and last but not least

- the lecturers, for their efforts in presenting hard material in a clear and pedagogical fashion, and also for writing up their lecture notes.

Costas Bachas
Adel Bilal
Michael Douglas
Nikita Nekrasov
François David