ESF Scientific Report

String Theory: Formal Developments and Applications

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Directors:

Laurent Baulieu,
Laboratoire de Physique Théorique et Hautes Energies
Université Pierre et Marie Curie,
Paris VI, 4 pl Jussieu, 75005 Paris, France

Eliezer Rabinovici,
Racah Institute of Physics
Hebrew University,
Jerusalem, Israel 91904

Michael R. Douglas,
Simons Center for Geometry and Physics
Stony Brook University, Stony Brook, 11794 USA;
and I.H.E.S., Le Bois-Marie, Bures-sur-Yvette, 91440 France

Pierre Vanhove
Service de Physique Theorique, Orme des Merisiers
CEA/Saclay 91191 Gif-sur-Yvette Cedex, France
and I.H.E.S., Le Bois-Marie, Bures-sur-Yvette, 91440 France

Jan de Boer
Institute for Theoretical Physics, University of Amsterdam
Valckenierstraat 65
1018 XE Amsterdam, Netherlands

Paul Windey
Same address as Laurent Baulieu

Scientific Content of the ESF School

The school covered recent progress in the very active area of superstring theory, quantum gravity and the theory of elementary particles, LHC physics, and applications of string theory to problems in condensed matter and nuclear physics.

These topics were covered by a total of 15 lecturers over nine days. Most speakers gave two lectures, and in addition there was a panel discussion in which students could ask questions about anything, and a "gong show" in which all the participants introduced themselves and their research in three minutes each.

The Large Hadron Collider at Cern has finally begun a physics run, colliding protons on protons at 7 TeV center of mass energy. Yves Sirois of the CMS Collaboration gave two lectures in which he reviewed the specifications of the LHC and the CMS and ATLAS detectors, described the currently active program of calibrating the detectors and reproducing existing Standard Model measurements, and prospects for discoveries, focusing particularly on the Higgs boson and on a fourth generation of quarks.

Three lecturers covered modern approachs to computing scattering amplitudes in gauge theory and gravity. Zvi Bern surveyed developments in the ongoing effort to compute amplitudes with more external legs and more loops, which will be important for the interpretation of collider data. A good deal of formal progress has been made by exploiting the simplicity of $N = 4$ super Yang-Mills and $N = 8$ supergravity, and Bern described recent work in which the known relations between the two theories have been dramatically simplified. These relations have given new life to the speculation that $N = 8$ supergravity could be finite in four dimensions, and Michael Green discussed the evidence for and against this idea coming from its relations to string theory.

Nima Arkani-Hamed discussed mathematical techniques involving integrations over complex Grassmannian manifolds which could represent amplitudes in $N = 4$ theory.

Nonperturbative aspects of four dimensional supersymmetric gauge theory were discussed by several speakers. Ken Intriligator and Zohar Komargodski gave a series of coordinated lectures which reviewed basic properties of the supersymmetry and superconformal algebras, and used these to derive general constraints on supersymmetric Lagrangians and their couplings to gravity. Intriligator also reviewed his work on simple models of supersymmetry breaking.

Nikita Nekrasov explained his recent work with Samson Shatashvili which ties the problem of finding and classifying ground states of these theories, with quantum integrable systems in one dimension.

Laurent Baulieu discussed the use of holomophic-form representations of spinors for topological field theory. He gave a new representation for the 10-dimensional super-Yang–Mills theory.

Compared to 2008, we put more emphasis on macroscopic and phenomenological applications of AdS/CFT. D. T. Son, one of the pioneers and leaders in the field, described outstanding theoretical problems in the theory of ultracold Fermi gases, and set out the basic framework for discussing such nonrelativistic problems. Robi Peschanski reviewed the duality between black holes in AdS and relativistic hydrodynamics, and used it to discuss quark-gluon plasmas, and cosmological models.

Several speakers discussed the physics of black holes in string theory. Andy Strominger gave two lectures on the Kerr solution and the developing theory of its dual conformal field theory. He also discussed the astrophysical evidence for rapidly rotating black holes, which are described by these solutions, and

conceivably could offer a new window into stringy physics. Ashoke Sen discussed refinements to the theory of state counting for highly supersymmetric black holes, distinguishing states by their global quantum numbers, and incorporating quantum corrections. Don Zagier, a world-renowned number theorist, gave an introduction to the mathematics of modular forms, which are one of the key tools in the subject.

Two speakers discussed topics relevant for the study of the landscape of solutions of string theory. Eliezer Rabinovici reviewed the theory of tunnelling in quantum gravity, and some of the outstanding questions in this theory which might be addressed using duality to gauge theory. Michael R. Douglas reviewed the idea of the space of quantum field theories, and discussed new conjectures and formal tools for working with this space.

The students had their opportunity to participate and interact. In addition to posing questions to lecturers, we held the traditional "Gong Show" in which every participant could speak about his or her work for three minutes, and had a "Wisdom Tree" session at which Ken Intriligator and Don Zagier shared their thoughts on any subject the students desired, with Eliezer Rabinovici as moderator. The cocktail of theorist , experimentalist and Mathematician proved to be most interesting. The students were moreover very involved in the discussion.

To summarize, it is the general feeling of the organizers, lecturers and students that the meeting was a success, striking the right balance between preparation for the exciting physics which will come out of LHC, while covering important recent developments in string theory and other formal theory. More than one of the speakers reminisced on their days as students and postdocs at Cargese, and were grateful for the chance to return. As organizers, we were happy to have the chance to maintain such a long-standing tradition, and are confident that our students will make important contributions in the coming era. We hope some of them will have the chance to return as lecturers in their turn.

Main Lectures

N. Arkani-Hamed (IAS, Princeton, USA): *Scattering amplitudes and the Grassmanians*

L. Baulieu (Paris Univ., France): *Off-shell closed multiplets with $SU(d) \subset SO(2d)$ covariance and 12 dimensional TQFT*

Z. Bern (University of California, USA): *Gravity as a Double Copy of Gauge Theory*

M. R. Douglas (Simons Center, Stony Brook, USA and IHES, France): *Spaces of Quantum Field Theories*

M. B. Green (DAMTP, Cambridge UK): *Properties of low energy graviton scattering amplitudes*

K. Intriligator (University of California, USA): *Topics in Susy Breaking and*

Mediation (part I)

Z. Komargodski (IAS, Princeton, USA): *Topics in Susy Breaking and Mediation (part 2)*

N. Nekrasov (IHES, France): *The Bethe/Gauge correspondence*

E. Rabinovici (Hebrew Univ., Israel): *Holographic Duals of AdS Bubbles*

R. Peschanski (IPhT Saclay, France): *Time-dependent AdS/CFT Holography: Applications*

A. Sen (Harish-Chandra Institute, Allahabad, India): *Black hole microstate counting and its macroscopic counterpart*

D. T. Son (INT, Univ. of Washington, USA): *Holography for Strongly Coupled Media*

Y. Sirois (Laboratoire Leprince-Ringuet, Ecole polytechnique, Palaiseau, France): *Physics at LHC*

A. Strominger (Harvard, USA): *Kerr and Kerr/CFT*

Don Zagier (MPI Bonn, Germany and Collège de France): *Mock Modular Forms and Black Holes*

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