

# Preface

The AdS/CFT correspondence, which states that  $D = 4, N = 4$  super Yang-Mills is equivalent to Type IIB superstring on  $AdS_5 \times S^5$ , is a remarkable manifestation of the holographic principle. This correspondence has given rise to a plethora of trends, approaches, techniques, and developments in nowadays physics. They range from “standard” pure theoretical aspects to those having interesting experimental applications. This correspondence is extremely useful for stringy interpretation of large  $N$  gauge theory with a subsequent application to problems of gravity physics such as entropy characterization of black hole physics. It also turns out useful to understand strongly coupled high-energy systems such as RHIC and LHC experiments, and intricate condensed matter systems.

Inspired by this success, one could try to involve another far reaching idea which is partially already present in the AdS/CFT correspondence. This idea is a duality which generalizes the notion of electromagnetic duality in Maxwell theory. Combined with supersymmetry, it leads to intriguing developments.

Namely,  $N = 2$  supergravity, deformed by a genuine supersymmetric completion of the  $\lambda R^4$  term, makes the previously “silent” ingredient play an active role. This  $(R \dots)^4$  counterterm in supergravity had its ups and downs since the time it was first proposed as a candidate for the UV divergence in  $N = 1$  supergravity. For  $N = 2$ , a linearized version of the candidate for the UV divergence was proposed a year later and its  $N = 8$  version was constructed 4 years later. Its gravitational part is the square of the Bel–Robinson tensor and it also has a term quartic in graviphotons. Its 3-loop UV finiteness was explained via the  $E_{7(7)}$  duality discovered by Cremmer and Julia.

This book is based upon lectures held on 25–28 March, 2013 at the INFN-Laboratori Nazionali di Frascati Breaking of supersymmetry and Ultraviolet Divergences in extended Supergravity Workshop BUDS 2013, directed by Stefano Bellucci, with the participation of prestigious lecturers, including E. Bergshoeff, M. Cederwall, T. Dennen, P. Di Vecchia, A. Karlsson, M. Koehn, B. Ovrut, G. Ruppeiner, A. Van Proeyen, R. Kallosh, P. Aschieri, and S. Ferrara; a special attention is devoted to discuss topics related to the cancelation of ultraviolet divergences in extended supergravity and Born-Infeld like actions.

All talks were followed by extensive discussions and related reworking of the various, contributions, a feature which reflects itself in the specific “flavor” of this volume.

Superconformal symmetry and higher derivative Lagrangians were discussed. It was stressed that the interest in higher derivative terms has several motivations:

- they appear as  $\alpha'$  terms in the effective action of string theory,
- they yield corrections to the black hole entropy,
- they provide higher orders in the AdS/CFT correspondence, and
- they give counterterms for UV divergences of quantum loops.

The current knowledge about general supergravity/supersymmetry theories was reviewed. The superconformal method (and in which supergravity theories we can use it) was discussed. Higher derivative supergravity actions and supergravity loop results were extensively re-examined. The Dirac-Born-Infeld–Volkov-Akulov actions were analyzed and the deformation of supersymmetry was provided as an example of an all order higher derivative supersymmetry action. Quantum calculations show that there are unknown relevant properties of supergravity theories. An interesting question is whether (broken) superconformal symmetry can be such an extra quantum symmetry. The nonexistence of (broken) superconformal-invariant counterterms and anomalies in  $N = 4, D = 4$  could in that case explain ‘miraculous’ vanishing results.

Progress toward determining the UV Behavior of Maximal Supergravity was then discussed extensively. After 35 years of supergravity, we can only now make very precise statements about the  $D = 4$  ultraviolet structure. No  $D = 4$  divergence of pure supergravity has been found to date. Supersymmetry forbids 1, 2 loop divergences, and pure gravity was found to be 1-loop finite, 2-loop divergent by Goroff and Sagnotti. Including matter, the theory becomes 1-loop divergent as it was demonstrated by ‘t Hooft and Veltman. Naively, supersymmetry allows for a 3-loop divergence.  $N = 8$  SG and  $N = 4$  SG are found to be 3-loop finite! In  $N = 8$  supergravity no divergence can be there before 7 loops. A 7-loop divergence in  $D = 4$  implies a 5-loop divergence in  $D = 24/5$ , a calculation currently in progress, which the groups involved reported at the Workshop.

If  $N = 8$  supergravity is perturbatively finite, the interest will lie in the reason behind the finiteness. Several possibilities arise for such a reason, a hidden new symmetry, for example. Understanding the mechanism might open a host of possibilities. Potential indications of hidden structures include the following fascinating options:

- Gravity is a double copy of gauge theories.
- Color-Kinematics according to which kinematics is a Lie algebra.
- Constraints from electric–magnetic duality.
- Hidden superconformal  $N = 4$  supergravity.

Let us recall that  $N = 4$  and  $N = 8$  supergravities arise as the low-energy limit of strings. String theory provides a consistent ultraviolet finite theory of quantum gravity. One could wonder if one can remove the string massive modes and address the question of ultraviolet behavior of pure supergravity. In the Workshop, also the String theory approach to UV divergences in supergravity was discussed,

in order to elucidate the role of supersymmetry in perturbative computation, as well as the role of non-perturbative duality symmetries in string theory.

This is the seventh volume in a series of books on the general topics of supersymmetry, supergravity, black holes, and the attractor mechanism. Indeed, based on previous meetings, six volumes were already published:

BELLUCCI S. (2006). *Supersymmetric Mechanics—Vol. 1: Supersymmetry, Noncommutativity and Matrix Models.* (vol. 698, pp. 1–229). ISBN: 3-540-33313-4. BERLIN HEIDELBERG: Springer Verlag (GERMANY). Springer Lecture Notes in Physics Vol. 698.

BELLUCCI S., S. FERRARA, A. MARRANI. (2006). *Supersymmetric Mechanics—Vol. 2: The Attractor Mechanism and Space Time Singularities.* (vol. 701, pp. 1–242). ISBN 13: 9783540341567. BERLIN HEIDELBERG: Springer Verlag (GERMANY). Springer Lecture Notes in Physics Vol. 701.

BELLUCCI S. (2008). *Supersymmetric Mechanics—Vol. 3: Attractors and Black Holes in Supersymmetric Gravity.* (vol. 755, pp. 1–373). ISBN-13: 9783540795223. BERLIN HEIDELBERG: Springer Verlag (GERMANY). Springer Lecture Notes in Physics Vol. 755.

BELLUCCI S. (2010). *The Attractor Mechanism.* Proceedings of the INFN-Laboratori Nazionali di Frascati School 2007. ISSN 0930-8989, ISBN 978-3-642-10735-1, e-ISBN 978-3-642-10736-8. DOI 10.1007/978-3-642-10736-8. Springer Heidelberg Dordrecht London New York. Springer Proceedings in Physics Vol. 134.

BELLUCCI S. (2013). *Supersymmetric Gravity and Black Holes.* Proceedings of the INFN-Laboratori Nazionali di Frascati School on the Attractor Mechanism 2009. ISSN 0930-8989, ISBN 978-3-642-31379-0, ISBN 978-3-642-31380-6 (eBook), DOI 10.1007/978-3-642-31380-6, Springer Heidelberg New York Dordrecht London. Springer Proceedings in Physics Vol. 142.

BELLUCCI S. (2013). *Black Objects in Supergravity.* Proceedings of the INFN-Laboratori Nazionali di Frascati School 2011. ISBN 978-3-319-00214-9, Springer Heidelberg New York Dordrecht London. Springer Proceedings in Physics Vol. 144.

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Stefano Bellucci

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