Preface

This book is an edited version of the review talks given in the Fifth Aegean School on the AdS/CFT correspondence, held in Adamas on Milos Island, Greece, from 21st to 26th of September 2009. The aim of this book is to present an advanced multiauthored textbook which meets the needs of both the postgraduate students and the young researchers, in the fields of Field Theory, String Theory, Gravity and Condensed Matter Physics.

The AdS/CFT correspondence is a powerful tool in studying strongly coupled phenomena in field theory using results from a weakly coupled gravity background. The principle of the AdS/CFT was developed within the string theory and it was proved to be very useful in describing strongly coupled phenomena in gauge theories like quark-gluon plasma and heavy ions collisions. Soon it was realized that its applicability can be extended, in a more phenomenological approach, to condensed matter systems and to systems described by fluid dynamics.

The selected contributions to this volume are aimed to describe the principle of the AdS/CFT correspondence in its field theoretic formulation in string theory, its applicability to holographic QCD and to heavy ions collisions and to give an account of processes in fluid dynamics and of phenomena in condensed matter physics, which can be studied with the use of this principle.

In the introductory part of the book the article by Christos Charmousis after introducing the basic properties of the anti de Sitter spacetime, it discusses the static black holes in this space, their basic properties and the novel topological effects due to the presence of a negative cosmological constant. The anti-de Sitter spacetime is a necessary ingredient to build up the gravity sector of the dual conformal field theory. To extract information about the transport coefficients of the boundary dual theory the properties of the background gravity sector should be known, best described by perturbation theory. The article by George Siopsis reviews the perturbations of black holes in asymptotically anti-de Sitter space and it shows how the quasi-normal modes governing these perturbations can be calculated analytically and it discusses the implications on the hydrodynamics of gauge theory fluids per the AdS/CFT correspondence.

The contribution by Philip Argyres introduces the basic concepts of the correspondence and its foundation in string theory. He first reviews the properties of d-dimensional conformal field theories and describes their relation to quantum gravitational theories on $(d + 1)$-dimensional anti-de Sitter spacetimes. The 't Hooft limit of $U(N)$ Yang-Mills theory is reviewed and then it is described how an appropriate limit of type IIB superstring theory with D3-branes can be used to motivate a precise and computable correspondence between a 4-dimensional conformal field theory and a quantum gravitational theory on $AdS_5 \times S^5$. He finally discusses an extension of this construction in which probe branes on the AdS spacetime are included.

The second part of the book deals with the holographic realization of the AdS/CFT correspondence. The first article presented by Elias Kiritsis reviews the applications of the correspondence to QCD. In particular it provides a detail review of holographic models based on Einstein-dilaton gravity with a potential in 5 dimensions. Such theories, for a judicious choice of potential are very close to the physics of large-N Yang-Mills theory both at zero and finite temperature. The model can be used to calculate transport coefficients, like bulk viscosity, the drag force jet quenching parameters, relevant for the physics of the quark-gluon plasma.

The next article by Romuald Janik in a pedagogical way presents the techniques of the AdS/CFT correspondence which can be applied to the study of real time dynamics of a strongly coupled plasma system. These methods are based on solving gravitational Einstein's equations on the string/gravity side of the AdS/CFT correspondence. These AdS/CFT methods provide a fascinating arena interrelating General Relativity phenomena with strongly coupled gauge theory physics.

The contribution by Veronika Hubeny discusses the fluid/gravity correspondence which originates from the AdS/CFT correspondence. This correspondence constitutes a one-to-one map between configurations of a conformal fluid dynamics in d dimensions and solutions to Einsteins equations in $d + 1$ dimensions. In particular, the bulk solutions describe a regular generic, non-uniform and dynamical black hole which at late times settles down to a stationary planar black hole. The iterative construction of such solutions is indicated and the key physical properties are extracted.

The article by Amos Yarom is on heavy ions collisions. This contribution provides a review of two particular applications of the gauge-gravity duality to heavy ion collisions. The first involves a study of the wake of a quark as it travels through the quark gluon plasma and its possible connection to measurements of jet correlations carried out at the relativistic heavy ion collider at Brookhaven. The second section provides, via the gauge/gravity duality, a lower bound on the entropy produced in a collision of two energetic distributions. This is then compared to particle multiplicity in gold–gold collisions.

This part of the book ends with the article by Jiro Soda. In his article, he explains how the AdS/CFT correspondence is related to the Randall–Sundrum braneworld models. There are two different versions of these braneworlds models, namely, the single-brane model and the two-brane model. In the case of the

single-brane model, the relation between the geometrical and the AdS/CFT correspondence approach using the gradient expansion method is revealed. In the case of two-brane system, he shows that the AdS/CFT correspondence play an important role in the sense that the low energy effective field theory can be described by the conformally coupled scalar-tensor theory where the radion plays the role of the scalar field.

The last part of the book consists of four articles and they discuss various aspects of the application of the AdS/CFT correspondence to condensed matter physics. In the first article Subir Sachdev reviews two classes of strong coupling problems in condensed matter physics, and describes insights gained by application of the AdS/CFT correspondence. The first class concerns non-zero temperature dynamics and transport in the vicinity of quantum critical points described by relativistic field theories. The second class concerns symmetry breaking transitions of two-dimensional systems in the presence of gapless electronic excitations at isolated points or along lines (i.e. Fermi surfaces) in the Brillouin zone.

The next article by Gary Horowitz gives an introduction to the theory of holographic superconductors. These are superconductors that have a dual gravitational description using gauge/gravity duality. After introducing a suitable gravitational theory, he discusses its properties in various regimes: the probe limit, the effects of backreaction, the zero temperature limit, and the addition of magnetic fields. Using the gauge/gravity dictionary, these properties reproduce many of the standard features of superconductors.

The string theory realization of holographic superconductors is given in the next contribution by Matthias Kaminski. After reviewing the basic D-brane physics and gauge/gravity methods at finite temperature he constructs the gravity dual of a D3/D7-brane system yielding a superconducting or superfluid vector-condensate. The corresponding gauge theory is $3 + 1$-dimensional $N = 2$ supersymmetric Yang-Mills theory with SU(N_c) color and $SU(2)$ favor symmetry and it shows a second order phase transition typical to superconductivity. Condensates of this nature are comparable to those recently found experimentally in p-wave superconductors such as a ruthenate compound.

The final article is by Tassos Petkou who discusses some attempts to construct a Kalb-Ramond superconductor. The article starts by explaining theholographic implications of torsional degrees of freedom in the context of AdS_4/CFT_3, emphasizing in particular the physical interpretation of the latter as carriers of the non-trivial gravitational magnetic field. It presents a new exact 4-dimensional gravitational background with torsion and argue that it corresponds to the holographic dual of a 3d system undergoing parity symmetry breaking. Finally, it compares the new gravitational background with known wormhole solutions—with and without cosmological constant—and argue that they can all be unified under an intriguing Kalb-Ramond superconductivity framework.

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Athens, July 2010 Lefteris Papantonopoulos

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