Scientific Report on the Workshop

« Paris Meeting
on Holography at Finite Density »

1 Summary

The holographic correspondence has established itself as an invaluable tool in the study of strongly coupled systems, by mapping them to appropriate gravitational models described by General Relativity or more generally String Theory. The workshop intended to explore the applications of holographic techniques to the study of strongly coupled materials.

2 Scientific content of the meeting

The meeting has brought together several of the leading world experts in the field of the applications of holography to condensed matter systems, and many of the most recent trends in research were presented. On the whole, the program of the workshop represented a significant cross-section of the research efforts that are currently being done trying to understand precisely how the holographic duality, that has proved very successful in the study of different aspects of large-N gauge theories, can be applied to strongly correlated fermion systems.

One of the intentions of the organizers was that of bringing together string theorists and condensed matter theorists interested in the topic ; this is very important in order to make progress, due to the interdisciplinary nature of the subject, especially for string theorists to direct their efforts of model-building into useful directions and towards the analysis of interesting open problems. There were two seminars along this line, by Jan Zaanen and Christos Panagopoulos, who explained different aspects of the theory and experiment of high-temperature superconductors. Zaanen reviewed the main ideas that have been proposed to explain high-Tc superconductors, whereas Panagopoulos revewed the experimental situation, focusing on the effects due to the disorder and the presence of glassy phases and ferroelectricity.

Several other speakers presented a variety of models in which one takes advantage of the power of the holographic duality to perform computations in a strongly coupled system.

Kachru introduced a variant of the classic Kondo problem, where a spin defect is coupled not to a gas of free conduction electrons but to a conformal field theory (N=4 SYM) ; Petkou used rotating black holes to describe rotating fluids in

order to understand the effects of vorticity, with applications to analog-gravity media (e.g. acoustic black holes) ; Gauntlett analyzed the instabilities of holographic superconductors to the formation of phases with spontaneous breaking of translational invariance ; Niarchos explained how one can model Josephson junctions by coupling together different AdS spaces ; Gouteraux reported on his explorations of the critical points that can be obtained in a class of models of gravity coupled to Maxwell and a dilaton field ; Evans analyzed the chiral symmetry breaking and deconfinement phase transitions in 2+1 dimensional models obtained by probe branes in AdS ; Semenoff suggested that a similar construction with probe branes can give models that bear a resemblance to graphene ; Starinets studied the properties of some low-energy fluctuations of the branes that behave exactly like the zero sound of a Fermi liquid ; Schalm described how the Fermi surface appears in the holographic description of finite-density systems and some possible critical points ; and O'Bannon suggested that N=4 SYM with a variable θ-angle can be thought of as a topological insulator, and described some checks of this idea using Wilson loops.

Still other speakers talked about more general or formal aspects of the holographic correspondence. Skenderis showed that one can make rigorous sense of holography in non-AdS spaces coming from non-conformal branes, using a generalized dimensional reduction. Rangamani discussed the peculiarities of the space of solutions for solitonic objects in AdS. Horowitz discussed the non-linear instability of AdS to the formation of a black hole and the implications for the thermalization of the dual field theory. DeBoer reported his results on the problem of providing the correct holographic renormalization for Lifschitz backgrounds that are supposedly dual to theories without relativistic invariance.

Finally, Hoyos discussed the Hall viscosity both from the point of view of effective theory with non-relativistic invariance and from holography.

3 Results and impact

The workshop provided a vast overview on the current understanding of the applications of holography to strongly coupled problems in low energy, finite density systems. The applications discussed included superconductors, Josephson junctions, graphene, non-Fermi liquids, and more general structures such as quantum critical points, non-relativistic scaling, and non-equilibrium instabilities. What emerged, is that the holographic duality is a very universal method for describing – at least qualitatively – a variety of different systems, some of which are still impenetrable to other approaches.

The talks and discussion during the workshop have made it clear that a fairly basic fundamental system of gravity, scalars and gauge fields in curved space-time

can be used to model systems with very different phenomenologies. In a sense, it is as general and powerful as what the Landau-Ginzburg (and more generally effective field theory) approach represent in the weakly coupled regime.

Now that it has proven possible to obtain qualitative results from the applications of ads/cft to condensed matter system, one of the big open questions is whether the field can move towards a more detailed and realistic, quantitative description of some of the systems under study. In order for this to be possible, one will probably have to abandon the simplicity of exact solutions, and construct more complex gravity duals that can be approached either perturbatively or numerically, with some phenomenological control parameters that can be fixed from experiment.

One of the most discussed topics has been the *strange metal* phase of high-T_c superconductors, a phase which appears to be governed by a quantum critical point. Much discussion was directed to understanding to which extent this can be described using holographic techniques. An important question is what are the quantities that can be used experimentally to probe this critical point, and to which of these probes can be realized in a holographic calculation. In particular, the role of disorder at low temperature seems to play a crucial role. This discussion has greatly benefited from the participations of the experts from the theoretical and experimental condensed matter community, who gave precious guidelines to the salient phenomenological features of the materials under consideration. Also, the relevance of fermionic operators and their different behaviors has been underlined by several speakers.

From the point of view of the formal development, the workshop has shown a consistent and successful effort in going beyond the well-established ads/cft techniques (in particular holographic renormalization) that have been previously applied in the context of conformal field theories, and in developing equally powerful methods for precision calculations in a wider range of situations, e.g. critical points with non-relativistic scaling. In this context the new concept of generalized dimensional reduction was shown to play an important role, that deserves further exploration.

Throughout the workshop, the level of discussion and interaction between scientists was consistently high. The format privileged a relatively small number of talks, all of which were of outstanding quality, and ample time for discussion. The workshop brought together a good portion of the experts on the subject – virtually all the European ones, and some of the most important American major experts, and allowed them to exchange ideas in a concentrated and effective way. Furthermore, a large number of postdoctoral researchers and graduate students have attended and participated in the discussion, and have greatly benefited from the close contact with the senior scientists and from the quality of the seminars. Thus, the workshop

has been a perfect occasion for graduate students, and more generally for young scientists starting their contribution in the field, to easily access available results from first hand sources and to have a complete picture of the existing state of the art.

Overall, all these points show that the event has been successful in advancing the field of holographic approaches to strongly coupled systems, by allowing a fruitful exchange of ideas among the major experts, by contributing to the training of younger scientists, and by giving a complete overview of the state of the art of the subject and defining its major goals and prospects for the future.

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APC, Paris

PROGRAM

Wednesday 16th

Morning Session

09:00 - 09:30	Registration	
09:30 - 10:15	Holographic Kondo and Kondo lattice models	S.Kachru
10:30 - 11:00	Coffee Break	
11:00 - 11:45	Holographic Fluids with Vorticity and Randers-Zermelo Geometries	T.Petkou
12:00 - 13:00	Two stories of magnetic catalysis	D.Tong
13:00 - 14:30	Lunch	

Afternoon Session

14:30 - 15:15	Holographic stripes and helical superconductors	J.Gauntlett
15:30 - 16:15	Holographic Josephson Junction Networks	V.Niarchos
16:30 - 17:00	Coffee Break	
17:00 - 17:45	Generalized Quantum Criticality in Einstein-Maxwell-Dilation theories	B.Gouteraux

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Thursday 17th

Morning Session

09:30	-	10:15	Observing the origin of superconductivity in quantum critical metals	J.Zaanen
10:30	-	11:00	Coffee Break	
11:00	-	11:45	A soliton menagerie in AdS	M.Rangamani
12:00	-	13:00	Lifshitz vs. Lifshitz	J.De Boer
13:00	-	14:30	Lunch	

Afternoon Session

14:30	-	15:15	A Turbulent Instability of Anti-de Sitter Spacetime	G.Horowitz
15:30	-	16:15	Symmetry Breaking in Strongly Coupled 2+1d Systems with E&B Fields	N.Evans
16:30	-	17:00	Coffee Break	
17:00	-	17:45	Hall viscosity and electromagnetic response	C.Hoyos

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Friday 18th

Morning Session

09:30	10:15	Magnetotransport studies on intrinsiacaly disordered superconductors	C.Panagopoulos
10:30	11:00	Coffee Break	
11:00	11:45	Holography from generalized dimensional reduction	K.Skenderis
12:00	13:00	Holographic fermions in D=3	G.Semenoff
13:00	14:30	Lunch	

Afternoon Session

14:30	15:15	Holographic zero sound at finite temperature	A.Starinets
15:30	16:15	On Holographic Fermi Liquids and Exciton-driven Phase Transitions	K.Schalm
16:30	17:00	Coffee Break	
17:00	17:45	Holographic Wilson Loops, Dielectric Interfaces and Topological Insulators	A. O'Bannon