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Scientific Report - Conference 'Gauge/Gravity Duality 2013' funded by ESF

1. Summary

The conference 'Gauge/Gravity Duality 2013' took place within the programme 'Holographic methods for strongly coupled systems' ('HoloGrav') funded by ESF, from Monday 29th July - Friday 2nd August 2013 at the Max Planck Institute for Physics (Werner-Heisenberg-Institute) in Munich, Germany, with 154 participants. The new concept auf Gauge/Gravity Duality creates new links between quantum field theory and gravity. It is based on string theory, a candidate for a 'Theory of Everything' within fundamental physics. However, Gauge/Gravity Duality now also has a wide range of applications in different areas of physics, ranging from elementary particle to condensed matter physics.

New methods which were discovered while working on formulating the 'Theory of Everything' may be used to describe physical systems with useful applications. This applies in particular to physical systems which are difficult to describe using established methods. A very important aspect of this new approach is the application of a *holographic principle*. This principle generates the three-dimensional picture of a hologram from a two-dimensional surface. Within string theory, a similar idea relates Einstein's theory of gravitation to quantum physics, for instance by mapping a four-dimensional quantum field theory to a gravity theory in five dimensions. This new relation is referred to as *Gauge/Gravity Duality*. These ideas led to deep insights into the nature of quantum gravity and have far-reaching and widespread applications, for instance also in condensed matter physics. Gravity solutions describing black holes may also describe the physics of metals and superconductors.

At the conference, the following subtopics were discussed in five hour-long overview talks, as well as in shorter plenary talks, in two parallel sessions and in a poster session: Supergravity, integrability, higher spin theories, entanglement entropy and applications to particle physics, the quark-gluon plasma and condensed matter physics. In this way, both fundamental and applied aspects of Gauge/Gravity Duality were covered and new links between both aspects were created.

2. Description of the scientific content and discussions at the event

The new theoretical approaches which were discussed at the conference are based on string theory. String theory is a promising approach to construct a unified theory of fundamental interactions, also referred to as 'Theory of Everything'. Within string theory, the elementary particles are not pointlike, but extended objects vibrating as a string. String theory provides a framework for a unified theory of fundamental interactions, i.e. for a unified description of the standard model of elementary particles together with gravity. This includes a theory of quantum gravity. Within this framework, in 1997 the Argentinian physicist Juan Maldacena proposed a new map between quantum theories without gravitation on the one hand and general relativity, the theory of classical gravitation, on the other. This map is a *duality*, i.e. it maps a strongly coupled quantum system to a weakly coupled gravity system. Strongly coupled quantum systems are ubiquitous in nature - both in elementary particle and in condensed matter physics. However, they are hard to describe using established methods. The duality is a result providing a better understanding of string theory at first. It was first derived for quantum theories of a very symmetric structure. For a couple of years by now, intense research is also carried out on applying the duality to strongly coupled systems in various areas of physics, considering systems present in nature and thus of less symmetric structure. There are already a number of convincing examples how the duality may be used as a tool, for instance for the shear viscosity of strongly coupled fluids, as well as for phase transitions in superfluids and superconductors. At the conference in Munich, two main aspects were discussed: 1) How far may the duality be generalized in order to explain experimental results not understood so far? 2) In what sense is the relation between string theory and quantum gravity relevant for these applications?

These questions were addressed in several blocks of different themes. The first of these themes was the application of Gauge/Gravity Duality to condensed matter physics. It was discussed how Gauge/Gravity Duality has lead to new ways of thinking about the definition of metals and insulators. Moreover it was shown how lattices and Drude behaviour may be implemented within Gauge/Gravity Duality, and implications for the quantum Hall effect were discussed. It was also considered how to implement Gauge/Gravity Duality for non-relativistic systems.

A second theme was the application to the quark-gluon plasma and hydrodynamics. In particular, several examples for anomalous contributions to the hydrodynamic equations for quantum liquids were presented. These vortex contributions to fluids were first discovered using Gauge/Gravity duality and provide a new link between supergravity and hydrodynamics.

Third, applications to elementary particle physics were considered. This included vector meson production at fixed momentum transfer, as well as the presentation of a new model for QCD the theory of strong interactions, in the limit of both large number of colours and large number of flavours. This

model displays new non-trivial scaling properties. Moreover, new methods for calculating scattering amplitudes were presented.

A fourth topic was the investigation of time-dependent systems and black hole formation. Gauge/Gravity Duality maps this to thermalization in quantum field theories and thus provides a new means to study non-equilibrium systems. This approach has important new applications both for the formation of the quark-gluon plasma and for quantum quenches in condensed matter physics.

The fifth topic related to more formal and fundamental aspects of Gauge/Gravity Duality. It was discussed how integrable structures allow for a further understanding of the duality at the level of string theory. An important recent development is the formulation of the duality for higher spin theories, realising the duality in a new context.

The sixth topic was the study of the quantum entanglement entropy using Gauge/Gravity duality. Several new approaches were proposed, for instance based on mapping the reduced density matrix to a thermal density matrix on hyperbolic space. Also, it was proposed that entangled particle pairs may be mapped to wormhole geometries.

It became clear how intimately these six topics are related both at the conceptual and the methodical level, which lead to lively discussions.

3. Assessment of the results and impact of the event on future directions of the field

The conference has lead to an intense exchange of scientists working on the more fundamental aspects of Gauge/Gravity Duality (Integrability, higher spin theories, two-dimensional conformal field theory) and the more applied ones (superfluids and superconductors, entanglement entropy, thermalization). In the discussions, both new ideas for applications as well as further studies for understanding the working mechanism of Gauge/Gravity Duality have emerged.

These questions were discussed by leading experts working in Gauge/Gravity Duality. Moreover, leading experts from neighbouring research areas also attended. These neighbouring areas included condensed matter physics, heavy-ion and quark-gluon plasma physics, general relativity and string theory. Consequently, new questions in these areas were identified to which an application of Gauge/Gravity Duality appears to be promising. At the same time, methods from string theory and general relativity were pointed out whose use is expected to lead to a deeper understanding of the working mechanisms of Gauge/Gravity Duality. In this way, the conference has contributed to sharpening the research directions in this new research area.

The conference has contributed to boosting the research area of Gauge/Gravity Duality and to enhancing its profile as a new approach to describing strongly coupled systems. We are looking forward to deepening the understanding of this new approach at the forthcoming workshops on this topic supported by the ESF HoloGrav Network.

4. Final programme of the meeting

The programme and a book of abstracts were sent by email to Holograv@esf.org. Please note also

the conference webpage,
http://ggd2013.mpp.mpg.de/index.html
where links to videos and the slides of all talks and a conference photograph are available.

5. List of participants

There were 154 participants. The complete list was sent by email to Holograv@esf.org.

With best regards,

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