

From thermal to quantum holography and back again

One of the most fascinating developments in contemporary theoretical physics is the so-called AdS/CFT correspondence which postulates the equivalence (also referred to as “duality”) of two apparently completely different theories – a non-gravitational quantum field theory and a theory involving gravity in a higher number of dimensions. Such a relation is often called “holography”, as gravity appears as a kind of “hologram” of the lower-dimensional theory. This allows for translating problems in quantum field theory into problems in gravity and *vice-versa*. A particularly useful feature of holography is that very difficult problems in quantum field theory, where the theory is strongly interacting get transformed into relatively “easy” classical problems in gravity. One can therefore solve these translated problems on the gravitational side, by e.g. solving numerically Einstein’s equations, and then translate the outcome into the original language of the quantum field theory. This led to numerous successes and insights into the dynamics of strongly interacting gauge theories e.g. the dynamics of quark-gluon plasma and the appearance of its subsequent hydrodynamic description, which is very relevant in the context of heavy-ion collision experiments performed currently at CERN.

There remain, however, physically important problems which are not amenable to this strategy. This includes, in particular, the process of hadronization, namely the transition of the hot quark-gluon plasma into hadrons or the process of bubble nucleation – the appearance of bubbles of the stable phase when the strongly coupled system cools and expands and undergoes a first order phase transition, which is relevant for the physics of the early universe. For these processes, the translated problems are expected to involve quantum effects on the gravitational side. One of the key goals of the research project is to explore quantum aspects of holography, such as Hawking radiation in that context and to develop techniques for addressing such problems within holography. The obtained insights into the process of hadronization or bubble nucleation would be useful not only from the theoretical perspective, but also in view of applications in heavy-ion collisions and the early universe.

The second key goal of the research project is again rooted in the quantum aspects of holography, but focuses on going in the opposite direction – from quantum field theories to gravity. This is particularly important, as the statement of holography can be understood as providing, in principle, a quantum definition of gravity using a lower-dimensional non-gravitational quantum field theory and the understanding of quantum gravity is one of the fundamental open problems in theoretical physics. Therefore any insight into the nature and properties of quantum gravity from holography would be very helpful. This problem is, nevertheless, very difficult as it requires a good understanding of both the lower-dimensional non-gravitational quantum field theory sufficient for performing computations, and of the dual geometrical interpretation for inferring properties of quantum gravity with matter.

The approach undertaken by the research project plans to consider exactly solvable quantum field theories at high temperatures. This has the additional benefit of allowing to study black holes on the gravitational side, whose behaviour at the quantum level is of utmost interest, as it involves an acute tension between quantum mechanics and gravity, manifesting itself e.g. in the so-called black hole information paradox. The research project builds upon a recent work of the Principal Investigator, which showed a mechanism for evading this paradox which is realized in the simplest setting of so-called Ising conformal field theory, where on the dual gravitational side matter was thrown into a three-dimensional black hole, got absorbed, but then surprisingly reemerged again. One of the key research themes of the project, will be the investigation whether a similar mechanism is applicable for other theories and in a higher, closer to our reality, number of dimensions. Insights into these questions would greatly increase our understanding of quantum gravity with matter, as well as the behaviour of black holes with respect to information loss.