The holographic glass bead game : from superconductivity to time machines

Bagrov, A.

Summary

The thesis is devoted to applications of holographic duality to qualitative analysis of problems in different areas of theoretical physics. After reviewing the basic principles of holography in the form of the anti-de Sitter/Conformal field theory (AdS/CFT) correspondence in Chapter 1, we proceed to its concrete applications in condensed matter physics, quantum chromodynamics, and the theory of non-causal spacetimes.

In chapter 2 we employ the AdS/CFT methods to formulate a theory of fermion driven ordering through pairing induced BCS-like superconductivity in holographic systems with Landau-like long-lived quasiparticles. We demonstrate that the AdS boundary dual of an interacting Dirac-Maxwell-scalar theory exhibits both superconductivity and the BCS/BEC crossover. If the scalar and fermionic field are decoupled form each other, they compete for the electric charge, and fermions suppress the scalar superfluid condensate. On the other hand, if the Yukawa coupling is switched on, fermions contribute additively to the total condensate value. A notable aspect of holographic fermions is that the bulk $U(1)$ gauge field dual to the boundary chemical potential also induces splitting of the fermionic bands (that might be considered as a bulk analogue of the Rashba spin-orbit splitting), which in turn leads to the fact that the pairing symmetry in the boundary field theory is $p + ip$. We also make an observation that the standard Gubser-Klebanov-Polyakov-Witten rule for the correlation functions cannot be used without modification once the bulk fields are coupled to each other.

In chapter 3 we turn our attention to the non-equilibrium physics of the formation of the quark-gluon plasma (QGP) in heavy ion collisions. For simplicity we use flat planar gravitational shock waves as a dual model of relativistic ions in the boundary field theory and study how a non-zero chemical potential affects the process of QGP formation. In order to circumvent the difficulties related to the full dynamical simulation of the bulk system of colliding shock waves, we stick to the formalism of trapped surfaces that allow us to obtain some estimates on properties of the "to-be-formed" black hole (dual to the deconfined boundary state) without solving the time-dependent Einstein equations. We find that as compared to the neutral case, electric charge reduces the multiplicity of

hadrons produced in the collision, and increases the temperature of the confinement/deconfinement transition.

In chapter 4 we address paradoxes of time traveling. Using holography we can calculate the two-point Green's functions in a non-causal quantum field theory. Such a theory is hard to construct ab initio, but its gravity dual is just a $(2+1)$-dimensional anti-de Sitter spacetime with two orbiting conical defects. This results in a spacetime with closed timelike curves. Applying the AdS/CFT-correspondence in its classical limit, we can simplify the analysis of the quantum dynamics at broken causality to just the analysis of the classical pseudo-Riemannian geometry of the bulk spacetime. Relying on the geodesic approximation we can perform the derivation of the dual field theory Green's function without implying any additional self-consistency constraints and we show that evolution of a quantum field can be controllable and non-pathological even in absence of causality.

Finally, in chapter 5 we give a summary of our results and put them in a wider context of the contemporary theoretical physics.