Popular science abstract

Anyone who has seen the Star Wars movie knows that a long time ago in a galaxy far, far away communication devices generated a three-dimensional picture: the so-called hologram. Holograms that we know from our everyday life are much simpler, as they encode three-dimensional data on a two-dimensional surface. One can find them easily on covers of DVD discs. Another example of three-dimensional data encoded on a plane is an ordinary map. In that case the longitude and latitude are encoded as coordinates of the map, while the altitude is marked with colour.

A very surprising discovery in theoretical physics in the last quarter of a century was finding physical models which exhibit similar behaviour. It turns out that some strongly coupled systems at microscopic distances exhibit dynamics which looks like that of astrophysical objects in spacetime with an additional spatial dimension. In that case, similar to the Star Wars communication device or a map, objects experiencing strong interactions in the lower dimension effectively depict higher-dimensional spacetime and gravitational phenomena. By analogy, this theoretical mechanism is called the "holographic principle". Here, the force of gravity appears in a somewhat illusory way as an effect of collective interaction of a large number of particles. Nevertheless, this allows for the application of computational techniques well-known from astrophysics to the description of important aspects of quantum systems which cannot be obtained with conventional techniques.

The research proposed in this project, based on the holographic principle described above, focuses mainly on applications to the description of the time evolution of strongly coupled quantum systems. The main research directions include deepening insights into so called *"transport coefficients"* (ordinary shear viscosity is an elementary example), and the dynamics accounting for phase transitions. The first direction uses the holographic principle to construct models of specific liquids, which are made of strongly interacting particles. Results will be of importance for the experiments of high energy heavy ion collisions (like the led ions).

The second research direction, as it was already pointed out, relates to the dynamics of systems which exhibit a phase transition. A simple example of a phase transition is boiling water. In that case the transition is of the first order, and does not require any unconventional theoretical methods. However, it turns out that in nuclear physics there are phase transitions of various kinds, including the first order transitions, which are not amenable to conventional approaches. In particular, there are difficulties in understanding transport phenomena, e.g. the heat transport. Holographic methods allow for effective study of these problematic aspects, confirming well established expectations as well as revealing new, unexpected effects.