Liquid water is made of a large amount of microscopic particles (H_2O molecules). However, from our perspective, it is nothing else than a continuum entity with the properties of what we usually call a fluid. Within its properties, for example, we find the propagation of waves. The physical theory describing the fluid dynamics is called hydrodynamics. The success of hydrodynamics to describe liquid water relies on the fact that is not necessary to know the microscopic details of the system. Instead, it is enough to assume that all the microscopic particles behave in a collective way. Therefore, the problem of finding the velocity of all these particles, is reduced to solving for the local velocity of the fluid, and thermodynamic variables as local temperature and density.

Top: Water in a state out of equilibrium, where the propagation of waves can be seen. Bottom: first image of a black hole, using Event Horizon Telescope. The luminous ring corresponds with the light bending due to the strong gravitational right outside the horizon. Credit: Event Horizon Telescope Collaboration

The goal of this project is to describe the hydrodynamic properties of electrons inside certain recently discovered materials, usually called topological semimetals. What is peculiar about the flow of electrons inside these materials, is the fact that exotic quantum effects allows to transport electrons inside a wire made of this material without loosing energy. The understanding of such properties will settle the ground for the design of more efficient devices to store energy, and might serve for the construction of quantum computers.

The origin of such exotic properties relies on certain similarities of the mathematical models describing the physical properties of the electrons inside the material and the ones describing the interaction of highly energetic particles, like the particles produced in colliders as the LHC in Geneva. The mathematical framework used to describe the high energy physics is called relativistic quantum field theory. In some sense, learning about the properties of such materials will provide us not only with important technological advances, but will help us acquire a deeper understanding of the fundamental laws of physics responsible for the structure of our universe.

Based on the similarities to the relativistic subatomic particles, we propose in this project to apply these techniques in the description of those apparently disconnected systems, like electrons inside a material. Within these tools we will use the holographic principle which relates black holes with the dynamics of quantum particles in hydrodynamic regime. The holographic principle, usually called gauge/gravity duality, surprisingly relates the dynamics of the events horizon of a black hole with the theories of fluid dynamics. In other words, black holes behaves as a fluid. In particular, holography becomes a useful tool when the interaction between particles is so strong, that all the standard computational techniques fail.

Finally, with this project we expect to predict the existence of new electronic transport properties in topological materials, and settle the ground for important technological advances in electronics.