The goal of the project is to find an effective description of the dynamics of quark-gluon plasma. Here on Earth quark-gluon plasma is a kind of fluid which is produced in experiments where heavy nuclei collide in accelerators such as the Relativistic Heavy Ion Collider (RHIC) at Brookhaven, or in the ALICE experiment at the LHC at CERN. In the aftermath of a nuclear collision typically tens of thousands of particles are registered. Already Fermi and Landau in the 1940s and 1950s had guessed that a statistical approach in terms of relativistic hydrodynamics should apply. Almost 20 years ago these expectations were decisively confirmed. It was not obvious that they would be, since we expect that at sufficiently high collision energies we should see a gas of weakly interacting quarks and gluons: this expectation follows from asymptotic freedom, which is one of the basic features of the strong force. However both at RHIC and the LHC we clearly observe collective effects characteristic of fluids, not gases: the distributions of detected particles carry information about the collision geometry (this is the so called "elliptic flow"). The fluid is called quark-gluon plasma, even though it is far from clear whether one can in a useful way regard it as a collection of individual quarks and gluons rather than a quantum state which does not possess such a particle description. It is also significant that the flow of quark-gluon plasma is dissipative: it is associated with entropy increase. This effect is due to viscosity of the fluid. It turns out that the viscosity of quark-gluon plasma is small relative to its entropy density, and for this reason one sometimes speaks of "the most perfect fluid in nature". It is also worth noting that in the ALICE experiment the temperature of quark-gluon plasma exceeds 5 trillion degrees.

The fundamental theory of the strong interactions, quantum chromodynamics, is a difficult theory to solve, and we do not have the mathematical tools necessary to effectively use it to describe quark-gluon plasma in a quantitative way. Fortunately, even far-from-equilibrium states of complex systems show certain universal properties. These properties, which follow from very general principles, are captured by the theory of relativistic fluid dynamics. The emergence of this kind of description has been the focus of intense research in recent years, primarily because of its applications to the physics of quark-gluon plasma. It is however an extremely important task to understand when this hydrodynamic description is valid and derive its parameters from the underlying microscopic theory, even in some approximate way. One surprising fact which has emerged is that some physical quantities behave in a universal way (independently of initial conditions), which can be stated as the existence of attractor solutions which govern the dynamics even when the system is far from local equilibrium. This has also lead to the application of novel mathematical techniques known as the theory of resurgence.

In this research project we will formulate and explore models which provide a tractable theoretical laboratory where the emergence of the hydrodynamic behaviour can be studied. We plan to explore connections between causality and attractor solutions, and ways in which traces of the initial state can survive in the hydrodynamic regime. We also plan to explore the techniques of resurgence theory and the physical interpretation of its key features.