Many natural systems remain far from equilibrium by continuously exchanging fluxes of matter charge, energy, or information with their surroundings. Such processes lie beyond the realm of thermodynamics and the principles of equilibrium statistical mechanics do not apply to them. Are there some overarching rules governing non-equilibrium behaviour? How are steady states selected? Can one characterize the statistical properties of the large scale fluctuations far from equilibrium? Answering these questions is one of the major challenges of contemporary statistical physics.

Some progress has been achieved by solving microscopic models of interacting particle systems, by using techniques borrowed from quantum integrable systems (the Bethe Ansatz). At macroscopic scales, the framework of the Macroscopic Fluctuation Theory (MFT) has been proposed for locally diffusive processes, in which large scale statistical non-equilibrium fluctuations are encoded in a system of coupled non-linear partial differential equations. The MFT equations remained inextricable for twenty years. Recently, it was discovered that for some paradigmatic models, the equations can be exactly solved by the Inverse Scattering Transform, developed in the 1970's to study non-linear dispersive waves and solitons.

Understanding the precise connections between different scales of description and various forms of integrability poses challenging problems which are the subject of this proposal.