PUBLISHABLE BRIEF SUMMARY OF THE ACHIEVEMENTS OF THE PROJECT

Modern Physics experiments are often very complex machines which the experimentalists try to shield from the noisy outer environment to perform very sensitive measurements. This is the case for instance of the gravitational wave detectors which do show a variety of unpredictable transients in spite of the experimentalists' efforts to make them stationary and Gaussian. Starting idea of the RareNoise project is that non-equilibrium effects might play a role which have not been considered so far. At the same time, large is the interest in non-equilibrium Physics: systems which are not in thermodynamic equilibrium are all around us. Life itself is a non-equilibrium phenomenon, with live cells and organisms evolving in time. To contribute to the development of a theory of non-equilibrium systems, the RareNoise project investigates the statistical properties of very-low loss mechanical oscillators in non-equilibrium steady-states. This research connects widely separated fields of science: that of experimentalists engaged in the noise hunting of the most sensitive displacement sensors that human beings can build, that of theoreticians looking for microscopic descriptions of irreversible thermodynamics and that of scientists developing molecular machines.

The research is performed via mutually reinforcing approaches: theoretical analysis, numerical modeling and laboratory experiments. Firstly, we have proved the correctness of the fundamental and starting idea of the RareNoise project, ie that gravitational wave detectors must be considered as non-equilibrium systems: this results was achieved using the data collected in 3 years by the gravitational wave detector AURIGA. Then, via our 3-fold approach, we demonstrated that the energy equipartition law is violated dramatically in non-equilibrium steady states even close to equilibrium and in simple systems such as damped oscillators. This is a remarkable result since equipartition is one of the fundamental concepts of equilibrium Physics: even if there is no reason to expect energy equipartition to hold in no-nequilibrium systems, there is no generally valid theory of non-equilibrium phenomena that predicts the extent to which equipartition should be broken and a case-by-case analysis is necessary. In any event, close to equilibrium the effects of violating equipartition are commonly believed to be practically negligible. The fact that the energy equipartition principle is violated even in simple systems in steady states close to equilibrium broadens the borders of applicability of the non-equilibrium studies. The law we propose to illustrate how equipartition is replaced in a system like ours, when in non-equilibrium steady states, focuses on correlation between different observables which are absent at equilibrium: this may contribute to clarify some not understood effects observed in the gravitational wave detectors. We have also progressed in the theoretical framework needed for describing the thermodynamic properties of the non-equilibrium steady-states. In particular, we have shed light on the often confusing issue of effective temperatures, which are of interest, e.g. in the study of disordered systems.

Thus, with theoretical, numerical and experimental work, the RareNoise project contributed to the development of a comprehensive theory of non-equilibrium phenomena.