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Department B: Scientific Department

Project No.: 202680

Project Acronym: RareNoise

Project Full Title: Low-probability, large fluctuations of the noise in detectors of gravitational waves

ERC GRANT

Final Scientific Report

Start date of project: 01.07.2008

Principal Investigator name: Livia Conti

Host Institution name: Istituto Nazionale di Fisica Nucleare

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Grant Final Scientific Report

GENERAL INFORMATION

Project No.:	202680
Project acronym:	RareNoise
Project full name:	Low-probability, large fluctuations of the noise in detectors of gravitational waves
Period number:	2
Period covered - start date:	01.07.2008
Period covered - end date:	30.06.2013
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Principal Investigator name:	Livia Conti
Host Institution name:	Istituto Nazionale di Fisica Nucleare
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SUMMARY OF THE MAJOR PROJECT ACHIEVEMENTS OVER THE ENTIRE LIFETIME OF THE PROJECT

The RareNoise project investigates the vibration fluctuations of oscillators in nonequilibrium steady states due to standing heat fluxes. Final goal is to apply the gained knowledge to the case of ground-based gravitational wave detectors, which the project qualifies for the first time as nonequilibrium devices. The research proceeds along three approaches: experimental, numerical and theoretical.

The experimental work consists in realizing low loss mechanical oscillators in Aluminum or Silicon, subject them to stationary thermal differences by flowing heat fluxes around room temperature or cryogenic temperatures (namely around 77K and 4K), and measure their vibration fluctuations. The properties of the fluctuations are then compared with the equilibrium case in order to get an understanding of the nonequilibrium phenomenon.

Numerical work consists in developing molecular dynamics models in 1 and 3 dimensions of solid rods to perform numerically experiments analog to the real ones: again, the statistical jitter of the length is investigated with respect to temperature differences at its extremes. The models are also used to compute the observables which cannot be experimentally tested, but which are still useful in the characterization of the non-equilibrium state of the system, and of its noise in particular.

Theoretical work consists in the compendium of experimental and numerical results, as well as pure theoretical findings, to refine and develop the theory of non-equilibrium systems and give a prediction for the size of the non-equilibrium effects in gravitational wave detectors.

We progressed in the 3 kinds of research work, as detailed below for what concerns the project's main scientific and technological achievements.

Another outcome of the present project is represented by the formation of a group of researchers in nonequilibrium physics, capable to integrate theoretical, numerical and experimental expertise, in order to carry out theoretical modeling, numerical simulation, and experimental implementation. Some of them, postdocs, have moved to other groups offering new positions; others constitute now a consolidated team, formed by the initial members of the RareNoise team, who are staff personnel at the partner Host Institution, by a staff researcher at the HI and by a couple of young postdocs also at the Host Institution. Moreover, thanks to the results gained with the RareNoise project, the PI has started new collaboration with a group of young researchers, both theoreticians and experimentalists, at the Physics Department of the University of Padova, which is collocated with the HI.

Scientific achievements:

- We applied for the first time the theory of non-equilibrium statistical mechanics and of non-equilibrium fluctuations, in particular, to macroscopic object such as a gravitational wave detector. This is a truly novel and unconventional methodology. First, we analysed the active-cooling readout scheme used to keep the gravitational wave detector AURIGA at an effective temperature of 0.02K while in contact with a thermal bath at 4.2K: we showed that it sustains an energy flow through the system. Then, we studied the fluctuations of the power exchanged with the surroundings and verified, for the injected power, one of the recently developed fluctuation relations, by analysing the data collected by the detector in a time-span of 3 years. As a result we proved that at least the gravitational wave detector under study must be considered as a non-equilibrium system, which is the fundamental and starting idea of the RareNoise project.

- We clarified how the power spectra of the fluctuations of oscillators kept out of equilibrium by feedback mechanisms depend on the oscillator losses as well as on the feedback protocols. Building on the above mentioned result, we further investigated oscillators subject to two types of feedback mechanisms, one focusing on time shifts and one on phase shifts: a modified Langevin equation which includes memory terms was studied analytically in a non-equilibrium steady state and power spectral densities of the system's fluctuations were evaluated. This scientific achievement finds application in feedback-cooled devices as those employed in the effort of investigating experimentally the quantum behaviour of mechanical oscillators.