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Post-doc proposal

Thermal Fluctuations in a stationary out-of-equilibrium system

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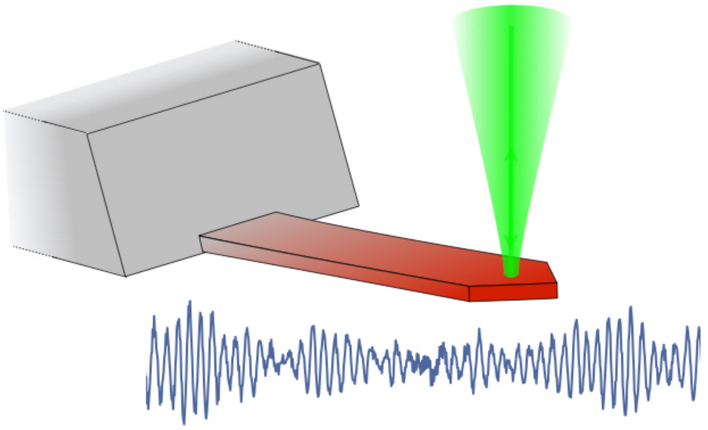
Schedule : Applications opening in November 2017

Abstract :

Statistical physics provides many tools to study systems in equilibrium, including the equipartition principle, or the Fluctuation-Dissipation Theorem (FDT). Those tools allow a detailed comprehension of thermal fluctuations, whose effects are more and more visible while we focus our interest on smaller and smaller systems (bio-physical processes or nanotechnology for example). However, equilibrium situations are rather the exception than the norm, and the question of thermal fluctuations in those out-of-equilibrium systems is much more difficult to tackle.

A common situation is a system submitted to a stationary heat flux. In a fluid for example, heat transfer triggers most of the time a motion of the medium (convection), and an increase of fluctuations with respect to an equilibrium situation. In a solid, contradictory observations have been made. For longitudinal deformation of a beam submitted to a moderate heat flux ($\Delta T \sim 10K$), L. Conti and co-workers [JSTAT P12003, 2013] observe an increase of fluctuations with respect to a system at equilibrium with the same mean temperature $T \sim 300K$. For the flexion modes of a silicon beam, we observe on the contrary a deficit of fluctuations [PRE **95**, 032138, 2017], for heat fluxes much larger ($\Delta T \sim 500K$, with a minimum temperature around the room one). We propose an extension of the FDT to systems with a temperature and dissipation that are not uniform in space. This framework accounts nicely for our observations, but not for those of the Italian group.



This proposal aims at extending our experimental and theoretical study of this system, to probe the robustness of our model and attempt to clear the contradiction between the observations. A silicon micro-cantilever submitted to a heat flux is indeed an ideal toy model to study out-of-equilibrium thermal fluctuations: it is small enough for its fluctuations to be 'easily' measurable, its degrees of freedom are easy to identify and decoupled from each other, and it is large enough to have a non uniform temperature. With the current experimental set-up, we can reach the melting temperature of silicon (1400°C), while maintaining the clamping base at room temperature. Several paths will be explored to continue the study:

- We will study (experimentally and theoretically) the modification of fluctuations of torsional modes of a cantilever due to a heat flux, to test the robustness of our approach to various deformations.
- Our initial measurements will be extended to a larger temperature range, by cooling the clamping base to cryogenic temperatures (10K), increasing this way the contrast between the minimal and maximal temperatures: from a factor 5-6 today (from 300K to 1700K), we could reach a factor greater than 100 (from 10K to 1700K). These experiments will be useful to explore in detail our model, giving more insights in the role of dissipation contrasts.
- Spatial distribution of dissipation is a corner stone of our model, and potentially allows one to tune the relative amplitude of the thermal fluctuations of different vibration modes of a mechanical system. Through controlled modifications of damping processes along the cantilever length, we will try to demonstrate this effect.
- Beyond measurements on a cantilever in vacuum, we will study the case of a system in contact with a gas, to explore the fluid-structure impact. The interpretation of the thermal fluctuations requires in this case an independent measurement of the temperature field, which we will realize with spatially resolved Raman diffusion studies.

All those measurements and models should in the end offer a thorough and original insight in this hot research topic. Numerous offside tracks to the central subject are possible: local phase transitions thanks to the control of the temperature of the tip of an atomic force microscope, study of the nucleation dynamics of a water meniscus at the scale of a unique nanometric contact, tribology of carbon nanotubes, instrumentation and metrology in nano-sciences…