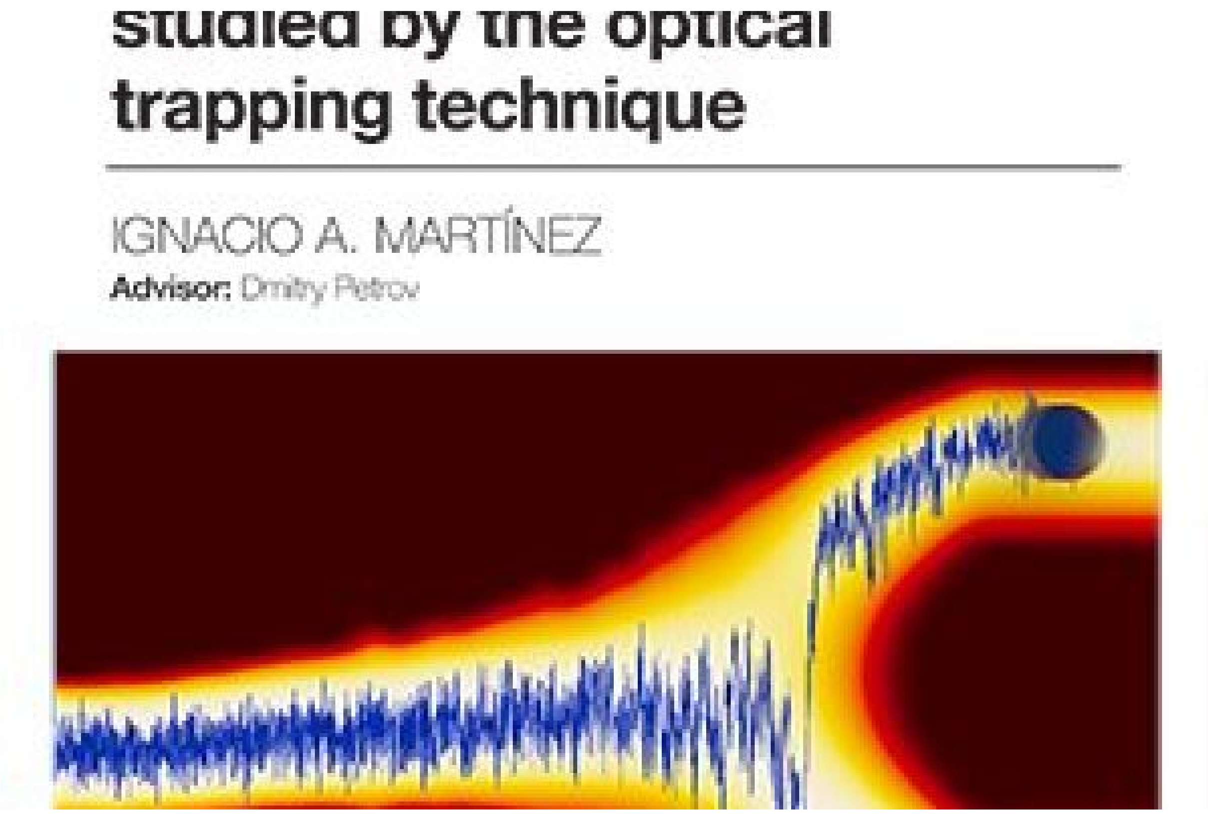

PhD Thesis Defense IGNACIO A. MARTINEZ 'Noise Assisted Effects In Physics And Biophysics Studied By The Optical Trapping Technique'

IGNACIO A. MARTINEZ

April 25, 2014

Friday, April 25, 11:00. ICFO Auditorium

IGNACIO A. MARTINEZ

Optical Tweezers

ICFO-The Institute of Photonic Sciences, SPAIN

Almost two centuries after the first observations of Robert Brown, the study of systems ruled by noise has become a significant part of modern physics and other so diverse situations, such as the stock market, personal networks, ecosystems, etc. In particular, we focus on the so-called small systems, where the thermal fluctuations determine the dynamics and energetics of the system. Examples of this scale are biopolymers, such as DNA or RNA, molecular motors, living cells or colloidal particles in suspension. As the energy exchanges between a small system and its environment are of the order of magnitude of thermal fluctuations, apparent violations of the classical laws of thermodynamics appear. We have studied the role of noise in biological and physical systems. As the main experimental tool we have used the optical tweezers technique, which allows one to exert forces in the pN range, as well as to spatially confine the studied objects improving the accuracy of the experiments. A highly focused laser beam creates a time and space controllable optical potential profile. This permitted to investigate noise assisted effects in different scenarios. Two biological systems were considered, namely, single DNA molecule and single bacterium. We showed that the motion of the stretched DNA molecule in the entropic regime (forces below 5 pN) includes an additional noisy component whose spectral power is proportional to 1=f . The presence of this noise may be related with changes of the probability of folding and unfolding events when the DNA strand is extended. On the other hand, we studied the trajectory of single bacteria, whose motion includes inherently noisy components. Using a novel technique with only one optical trap we measured the dynamics of a trapped single bacterium S. enterica. We found that the trajectory within a single trap can reveal the different behavior of the samples. In addition to the validation of our technique, we have characterized the phenotype of mutant cheV in anaerobic conditions.

In the second part of the thesis, we studied stochastic thermodynamic using a micron-sized dielectric sphere.The control of the temperature in such experiments has a key importance to understand the energetics of the small systems. We suggested a novel technique to control the kinetic temperature of a sphere by applying of an external force with the same power spectral density (PSD) as one of the thermal noise. We experimentally tested our hypothesis in equilibrium, measuring the position histogram and PSD of the microsphere, and out of equilibrium, implementing a protocole to test Crooks theorem. We conclude that our technique allows one to control the kinetic temperature of a Brownian particle over a wide range of values, from room temperature to several thousand Kelvin with high temporal accuracy. The most obvious application of this technique is the realization of nonisothermal processes. Among them, an adiabatic process is essential although controversial in small systems. We study its meaning in a colloidal particle experiment, paying attention to the consequences of the overdamped approximation.

Finally, we could realize for the first time the Carnot cycle, using a colloidal particle in a liquid as a working substance.

The effect of the thermal bath is also present in the thermodynamics of information. In the last chapter, we considered the derivation of a universal equivalence between the energetics of a process and the probability of a system to choose it among other options. The obtained expression can be considered a generalization of the Landauer limit. We tested our theory in an experiment where a continuous transition from a single well to a double well potential produces a symmetry breaking affecting a Brownian particle. Moreover, combining two of the process, we were able to achieve the first realization of a Szilard engine based on symmetry breaking and symmetry restoration.

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Thesis Advisor: Prof. Dmitri Petrov (Passed Away 3-Feb-2014)