Entropy production and 2nd law in stochastic systems under continuous feedback control

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Entropy production (EP) in small stochastic systems under feedback control is an issue that has attracted much theoretical attention over the last few years, at the crossroad between statistical physics and information theory [1]. In this talk, I will present some recent work in collaboration with T. Munakata (Kyoto Univ.) that focuses on systems in which measurements and actuation are performed *continuously*, i.e., repeated with a period shorter than the characteristic time scales of the dynamics - typically an underdamped Langevin dynamics. Two problems are investigated that correspond to actual situations:

i) the influence of measurement errors (i.e. detector noise) in a *cold damping* setup in which a harmonic oscillator (e.g. the cantilever of an AFM or the mirror of an interferometric detector) in contact with a heat bath is submitted to a velocity-dependent feedback force that reduces the random motion. We distinguish whether the sensor continuously measures the position of the resonator or directly its velocity (in practice, an electric current). We also assign a relaxation dynamics to the feedback mechanism and compare the apparent entropy production in the system plus the heat bath to the total entropy production in the super-system that includes the controller [2].

ii) the influence of a time delay between the input signal and the output control action, a situation that occurs in many biological or artificial systems (e.g. in the control of vision and posture, or in laser networks). We show that the system spontaneously settles into a nonequilibrium steady state where entropy is permanently produced (cooling or heating is achieved depending on the delay). However, since the feedback makes the dynamics non-Markovian, this supposes to properly revisit the definition of EP as a measure of time-irreversibility within the framework of stochastic thermodynamics [3].

In both cases, we adopt the standpoint of the controlled system and, in the spirit of [4,5], we identify the *entropy pumping* contribution that describes the influence of the external agent and that modifies the second law of thermodynamics and the fluctuation theorems.

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[3] T. Munakata and M.L. Rosinberg (in preparation).
[4] K. H. Kim and H. Qian, Phys. Rev. Lett. **93**, 120602 (2004); Phys. Rev. E **75**, 022102 (2007).
[5] T. Munakata and M. L. Rosinberg, J. Stat. Mech. P05010 (2012).