M2 INTERNSHIP or THESIS PROPOSAL

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Uncertainty relations for non-equilibrium fluctuations in biological systems

Today, a mature theory of Thermodynamics is available, based on the solid mathematics of Stochastic processes, called Stochastic Thermodynamics. This theory is able to predict the statistical properties of fluctuations, in small or large systems arbitrarily far from equilibrium. The fundamental observables of non-equilibrium systems are currents, and their statistics has been the focus of intense research for many years. Recently, a set of thermodynamic uncertainty relations have been obtained [1] and then proven rigorously using large deviation theory [2]. These relations constrain the fluctuations of all currents by the average dissipation. Therefore, these relations express a fundamental trade-off between precision and dissipation, which could be a central design principle for living systems. Indeed, living systems often seek to achieve selectivity for their function and reproduction, but there is a thermodynamic cost for that (see extensive literature on the specificity of chemical reactions in the context of proofreading for instance where a similar trade-off occurs).

Inspired by these developments, we have recently derived analogous uncertainty relations for equilibrium systems, which also contain a trade-off, albeit of a different kind [3]. During this internship/thesis, we propose to explore further consequences of these non-equilibrium uncertainty relations. We want to study particularly systems described by continuous dynamics of the Langevin/Fokker Planck type, which have many applications in experimental systems. One of such applications, concerns the fluctuations of gene expression, which are now accessible to single cell experiments as in for instance E. coli.

To summarize, while basic knowledge on Langevin/Fokker Planck equations is required for this internship, knowledge of more advanced topics like large deviation theory is not required. However, a curiosity towards the application of Statistical Physics ideas to biological systems would be a plus.

References:
[1] A. C. Barato and U. Seifert, Thermodynamic uncertainty relation for bimolecular processes, Phys. Rev. Lett. 114, 158101 (2015).
[2] T. R. Gingrich, J. M. Horowitz, N. Perunov and J. England, Dissipation bounds all steady-state current fluctuations, Phys. Rev. Lett. 116, 120601 (2016).
[3] J. Guioth and D. Lacoste, Thermodynamic bounds on equilibrium fluctuations of a global or local order parameter, in press for Europhys. Lett., https://arxiv.org/abs/1610.04739