Lecture 1: ***Quantum Thermodynamics'*** *take on* ***Foundational issues*** *of* ***Statistical Mechanics***

Abstract:

Quantum Thermodynamics (QTD) in a stricter definition is the study of the thermodynamical properties of quantum many-body systems. In trying to convey the contents and meanings of this new discipline by fusing these two terms *quantum* and *thermodynamics* together, we see immediately there are intrinsic dislocations or even contradictions. Namely, while quantum deals with the microscopic world and quantum features manifest usually at low or zero temperatures, thermodynamics was formulated mainly in the context of classical phenomena, is restricted to the macroscopic realm, and usually functions at high enough temperatures where thermal properties prevail over quantum. So, like the names of many other physics subfields which were coined for convenience (quantum gravity, to give one example), quantum thermodynamics is a misnomer in many senses. However, these dislocations are interesting because they bring out **foundational issues at the micro-macro (m-M) and the quantum-classical (q-C) interface**. The more fundamental theory which can encompass both aspects and offer more than conventional thermodynamics (TD) based on classical mechanics, is ostensibly *not* quantum statistical mechanics (its quantum aspect referring only to boson-fermion statistics, but ignoring the most important quantum phase information completely) but the **nonequilibrium dynamics of open quantum systems**. Using a Brownian motion model which is exactly solvable [1] we come to a better understandings of several foundational issues at the m-M/q-C interface from this broader perspective [2]. This enables us to reexamine the conditions for the applicability of the (very commonly used) canonical ensemble (which are actually very special), the properties of the thermodynamic quantities, the soundness of the relations and the validity of the laws. Our approach is fundamentally different from many ongoing work on QTD whose setup assumes that the combined system and its environment is in a thermal state throughout [3][4]. This latter setup is popular because it conveniently provides the conditions of thermodynamics for the quantum closed system ab initio. However, it is not easy to extract the dynamics and describe the thermodynamics of the system in contact with an environment which can deviate from thermal equilibrium. In the second lecture I will address bigger issues ingrained in the *quantum* and in *thermodynamics*: choice of collective variables in an effective theory, the essences of emergence [5], fluctuations and stochasticity, nonlocality, non-Markovianity, and in this light re-examine the presumptions and implications of the thought-provoking "gravity as thermodynamics" proposal.

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[2] R. Kosloff, "*Quantum thermodynamics: a dynamical viewpoint*", Entropy 15, 2100 (2013).

[3] J. Gemmer, M. Michel and G. Mahler, "*Quantum Thermodynamics - Emergence of Thermo-dynamic Behavior within Composite Quantum Systems*", 2nd Edition (Springer Verlag, Berlin, 2004).

[4] U. Seifert, "*First and second law of thermodynamics at strong coupling*", Phys. Rev. Lett. 116, 020601 (2016).

[5] B. L. Hu, "*Emergence: Key Physical Issues for Deeper Philosophical Inquires*" [arXiv:1204.1077]

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