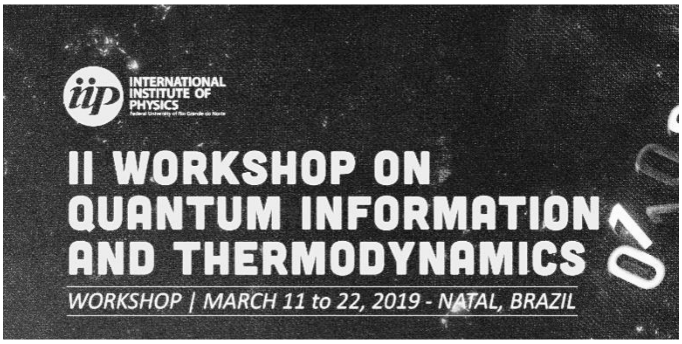

Panel Discussion (18 March 2019)

Panelists:

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- Jens Eisert
- Eric Lutz

Moderator:

- Gerardo Adesso

What is quantum thermodynamics?

- The thermodynamics of off-diagonal matrix elements (in the energy basis)
- It’s about control at the nanoscale where the off-diagonal elements matter most
- It’s about simple laws that also regulate the coherence of the system
- Includes information thermodynamics: where entanglement and other resources play a role
- There’s been lots of focus on the system. But what about quantum baths?

What is *quantum* in quantum thermodynamics?

- Perhaps we should not obsess with this question…
- For example, the single-ion heat engine is fundamentally classical, still a significant advance
- We have measures of quantumness in thermal machines, but their operational relevance is still unclear
- What is genuinely quantum is the fact that you can exploit quantum resources to do things that cannot be done classically
- Still we haven’t got a killer application yet. Perhaps cooling is a practical candidate
- For quantum quantum thermo: we need experimental realisations and evidence that coherence matters

Is there a quantum thermodynamics community or is it still too fragmented?

- There is still a gap between resource theories vs open systems approaches but it’s finally getting bridged
- APS has “Quantum Thermodynamics” tag so it’s a community! There’s external recognition
- Yes, it’s a community, we attend the same events, we have access to same terminology. But language is still not universal, leading to fragmentation, although it’s improving
- There’s another gap to bridge: an external one, we should keep in touch with the broader physics community, not risking to become insular

What do we need to develop the community and the field further?

- To develop further we need <u>more experiments</u>. Should be meaningful experiments, not just proof-of-concept demonstrations of theoretical results, or “boring” single-particle setups
- What experiments are really meaningful? Those involving many-body systems, which demonstrate effects not be computable theoretically. Eg cold atom quantum simulators
- Maybe the fact that we can control quantum systems is already progress (even beyond possible advantages over classical systems) but does a quantum thermo perspective brings something new?
- Quantum thermo experiments should demonstrate the conversion from microscopic degrees of freedom (info) to macroscopic degrees of freedom (energy etc)
- Example: the atom maser interpreted as thermal machine (60 year old result). But does the quantum thermodynamical interpretation provides added value to these seminal studies?
- Once we have an experimental realisation of quantum thermo, how do you certify it’s quantum? (think of D-Wave for quantum computing): we need tools for verification

Looking back: what are the top breakthrough achieved in the field in the past 10 years?

- Quantum engines which apparently do better than classical engines
- Thermalisation: a quantum system behaves like a classical one if it's complex enough (equilibration of quantum systems)
- Understanding of fluctuation theorems at the general fundamental level
- Realisations of quantum transport between reservoirs in cold atoms setups
- Increased understanding of quantum coherence and quantum correlations and their role as resources
- Many-body thermalisation: ergodicity breaking, slow equilibration etc.
- These are all advances but maybe we had *no* real breakthrough at all! Progress has been mostly incremental. Perhaps we have not yet defined the field and its universal laws
- Have we already asked the most meaningful questions or do we still need to find a way to open Pandora's box?
- A breakthrough could be the very fact of having attracted the interest of experimentalists (and funders, e.g. FQXi) to address meaningful questions in quantum thermodynamics

Looking forward: what are the top open questions to tackle in the next 10 years?

- Construction and verification of quantumness (or quantum advantage) for a quantum thermodynamical machine
- Formulating universal laws of quantum thermodynamics (taking into account coherence and correlations)
- How to measure thermodynamic quantities for many-body systems
- Resource theories need to get physical
- Cooling and other practical applications, and a better understanding of the mesoscopic regime
- Continuously operated engines
- Characterisation and experimental measurement of entropy production
- Understanding thermodynamics under strong coupling
- Realisation of non-equilibrium baths (beyond thermal)
- Quantum-classical correspondence for many-body systems, interacting vs non-interacting systems
- Characterisation of timescales: how long does it take for a system to equilibrate?
- Maybe devising a new thought-provoking paradox?

What can be the technological relevance and broader impact of quantum thermodynamics?

- We are too far from experimental progress to be able to claim or exploit any technological relevance. As usual in science, impact is impossible to predict in general
- Quantum thermometry can have an impact on society (e.g. healthcare)
- When miniaturisation in various technologies hits the quantum domain, what can happen? Good or bad features? Finding out provides motivation for further research
- Research in quantum thermodynamics is driven by fundamental questions, and we like it this way ☺