Tight Bound on Finite-Resolution Quantum Thermometry at Low Temperatures

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Abstract. We investigate fundamental precision limits for thermometry on cold quantum systems, taking into account constraints due to finite measurement resolution. We derive a tight bound on the optimal precision scaling with temperature, as the temperature approaches zero. The bound demonstrates that under finite resolution, the variance in any temperature estimate must decrease slower than linearly.

Keywords: Quantum thermometry, quantum thermodynamics, quantum sensing.

Precise thermometry is of wide importance in science and technology in general and in quantum systems in particular. Here, we investigate fundamental precision limits for thermometry on cold quantum systems, taking into account constraints due to finite measurement resolution. We derive a tight bound on the optimal precision scaling with temperature, as the temperature approaches zero. The bound demonstrates that under finite resolution, the variance in any temperature estimate must decrease slower than linearly. This scaling can be saturated by monitoring the non-equilibrium dynamics of a single-qubit probe. We support this finding by numerical simulations of a spin-boson model. In particular, this shows that thermometry with a vanishing absolute error at low temperature is possible with finite resolution, answering an interesting question left open by previous work. Our results are relevant both fundamentally, as they illuminate the ultimate limits to quantum thermometry, and practically, in guiding the development of sensitive thermometric techniques applicable at ultracold temperatures.

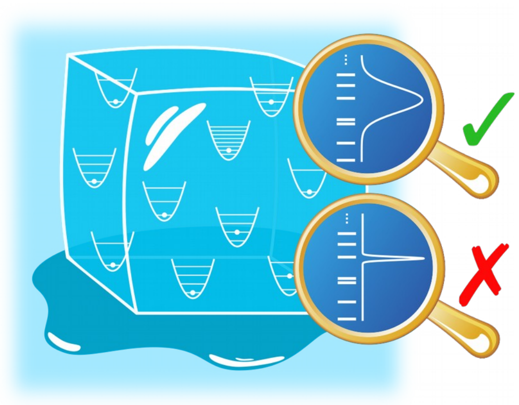

Figure 1 Finite measurement resolution is interpreted as an inability to sharply distinguish between consecutive system energy eigenstates and results in a non-trivial constraint on the attainable thermometric precision. For a macroscopic system with an effectively continuous energy spectrum, any measurement is subject to finite resolution and thus limited by the bound,we derive.

References

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