Stochastic Collisional Quantum Thermometry

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Abstract

We extend collisional quantum thermometry schemes to allow for stochasticity in the waiting time between successive collisions. We establish that introducing randomness through a suitable waiting time distribution, the Weibull distribution, allows us to significantly extend the parameter range for which an advantage over the thermal Fisher information is attained. These results are explicitly demonstrated for dephasing interactions and also hold for partial swap interactions.

Probe Based Thermometry

The maximum precision with which the temperature of the environment can be measured is determined by the quantum Cramer–Rao bound.

$$(\Delta T)^2 \geq \frac{1}{\mathcal{F}(T,\rho)}$$

For standard probe based thermometry (shown below) the quantum Fisher information is given by the thermal Fisher Information where C is the specific heat capacity of the probe.

$$\mathcal{F}(T,\rho) = \mathcal{F}_{th} = \frac{C}{k_B T^2}$$

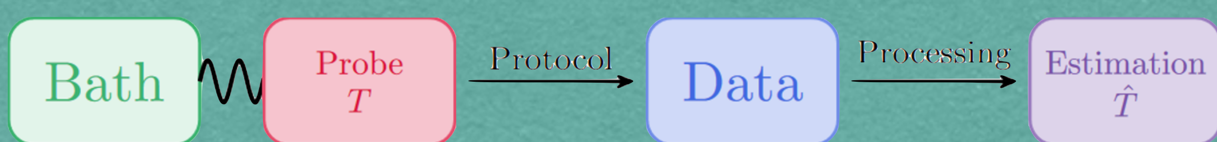

Figure 1: A standard probe based thermometry set-up[2]

Collisional Quantum Thermometry

The traditional probe based thermometry setup shown above can be combined with the framework of collision models. In this setup the measurements are performed on the auxiliary units after they have interacted with the probe. This setup allows for additional degrees of freedom such as the initial state of the auxiliary units, and the interaction with the probe. These additional degrees of freedom allow for significant improvement over the thermal Cramer-Rao bound[3,4]

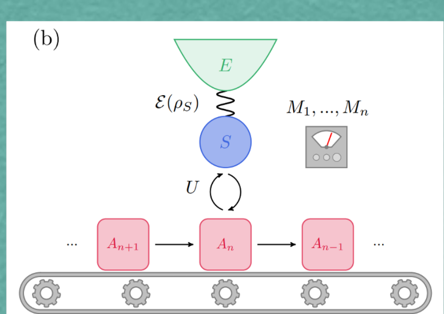

Figure 2: The collisional thermometry setup[2]

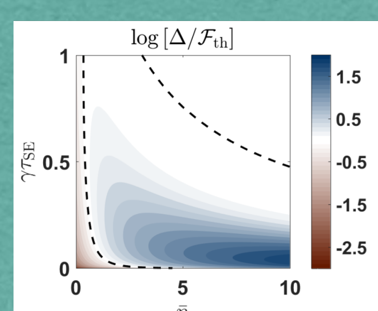

Figure 3: Ratio between the collisional and the thermal Fisher information[3,4]

Adding Stochasticity

One downside of using the quantum Cramer–Rao is that it is a local estimation scheme. This means that in order to achieve the maximum precision, the temperature must already be known with a high degree of certainty. In order to address this downside we added stochasticity to the collision model at the level of the waiting time between collisions. This stochasticity is modelled by the Weibull distribution:

$$p(t) = \frac{k}{\lambda}\left(\frac{t}{\lambda}\right)^{k-1} e^{-(t/\lambda)^k}$$

A large k gives a mostly deterministic waiting time, as k approaches 1 we get a spreading out of the quantum Fisher information, with a smaller peak, but a wider range of interaction strengths that achieve a meaningful advantage over the thermal Cramer-Rao bound.

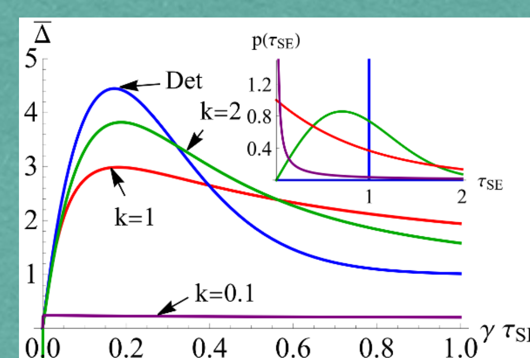

Figure 4: Quantum Fisher information for various waiting time distributions

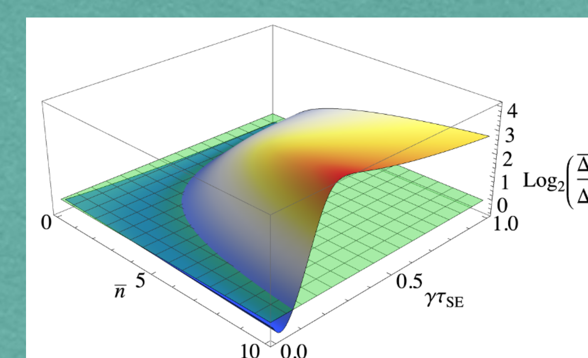

Figure 5: The performance of the k=1 distribution over various temperatures

References

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