Continuous measurements for adaptive qubit thermometry

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Collisional qubit thermometry

- Ground state qubits interact with bosonic bath
- Likelihood to be excited:

$$q_\tau(T) = \frac{1 - e^{-\gamma\tau \coth(E/2k_B T)}}{1 + e^{E/k_B T}}$$

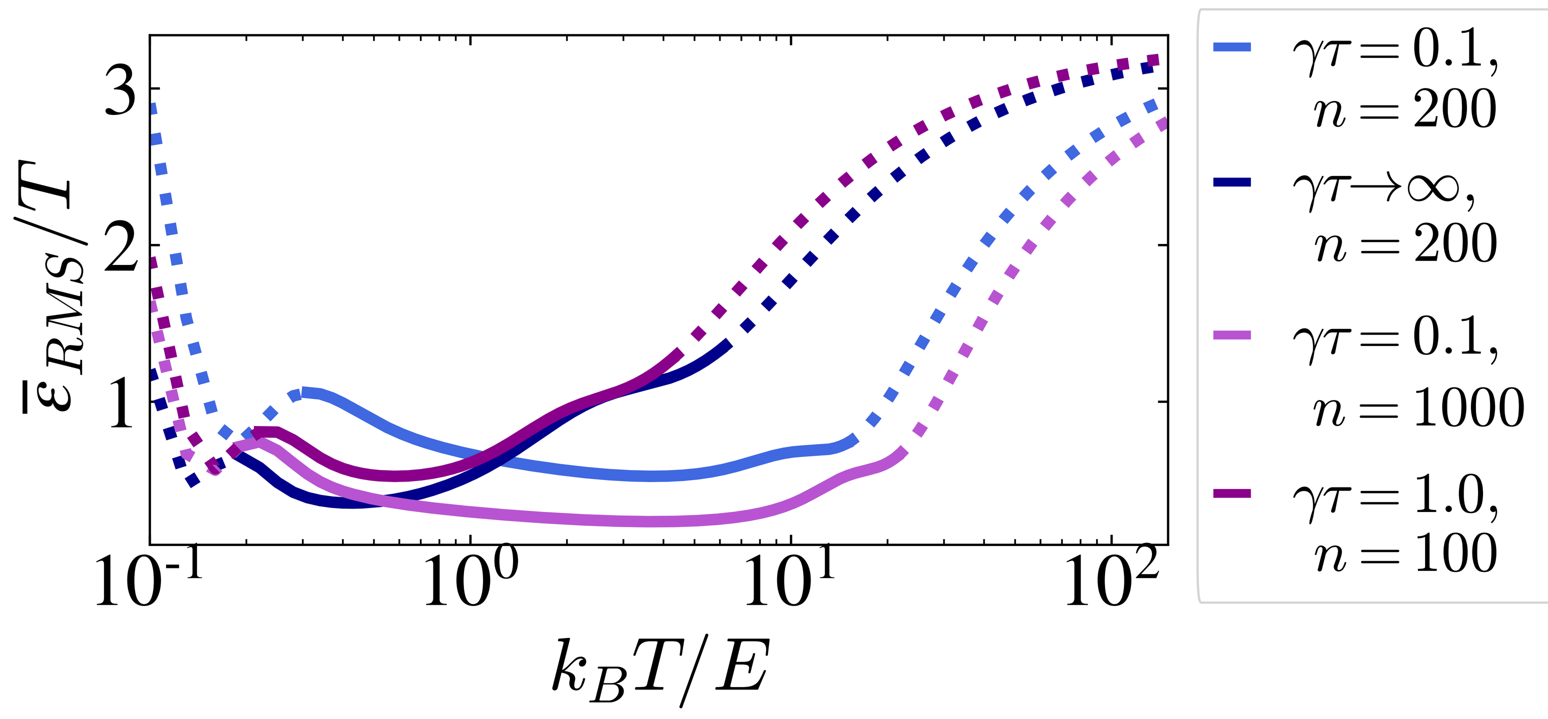
- Qubits are projectively measured in the energy basis.
- Use Bayesian estimation to deduce the temperature

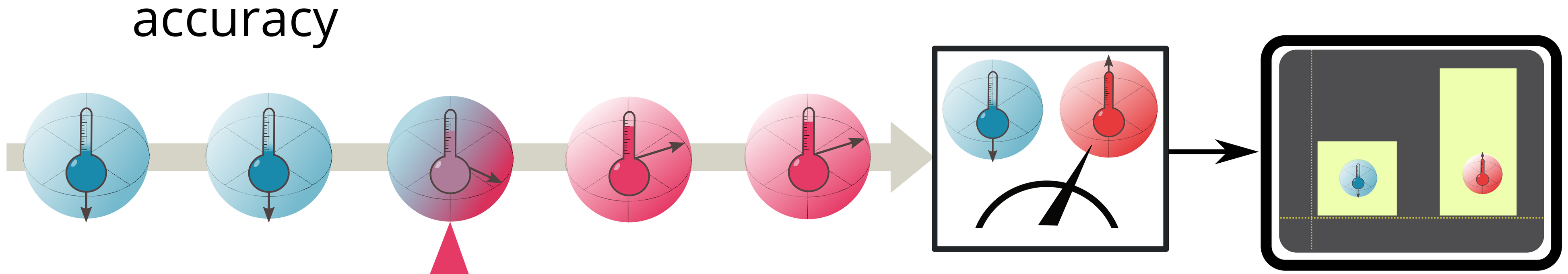
$$P(T|n) = \frac{P(n|T)P^{(0)}(T)}{\int_0^\infty \mathrm{d}T\, P(n|T)P^{(0)}(T)}$$

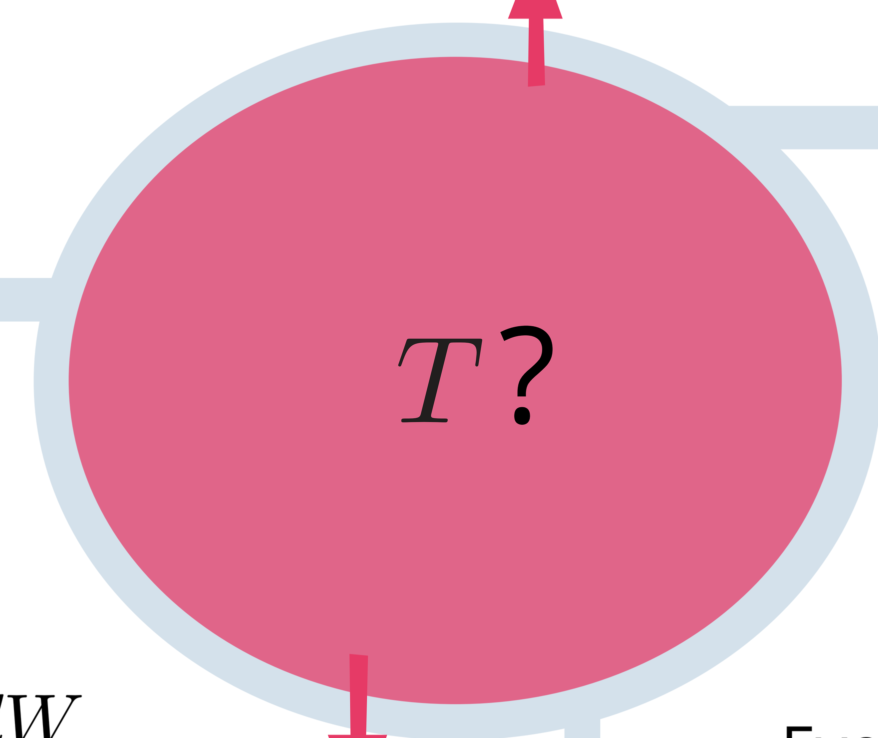
- Performance assesed by the deviation from the true temperature

$$\bar{\varepsilon}_{\mathrm{RMS}}(T) = \sqrt{\sum_n P(n|T)(\vartheta_n - T)^2}$$

Shorter interaction time → more measurements → improved accuracy







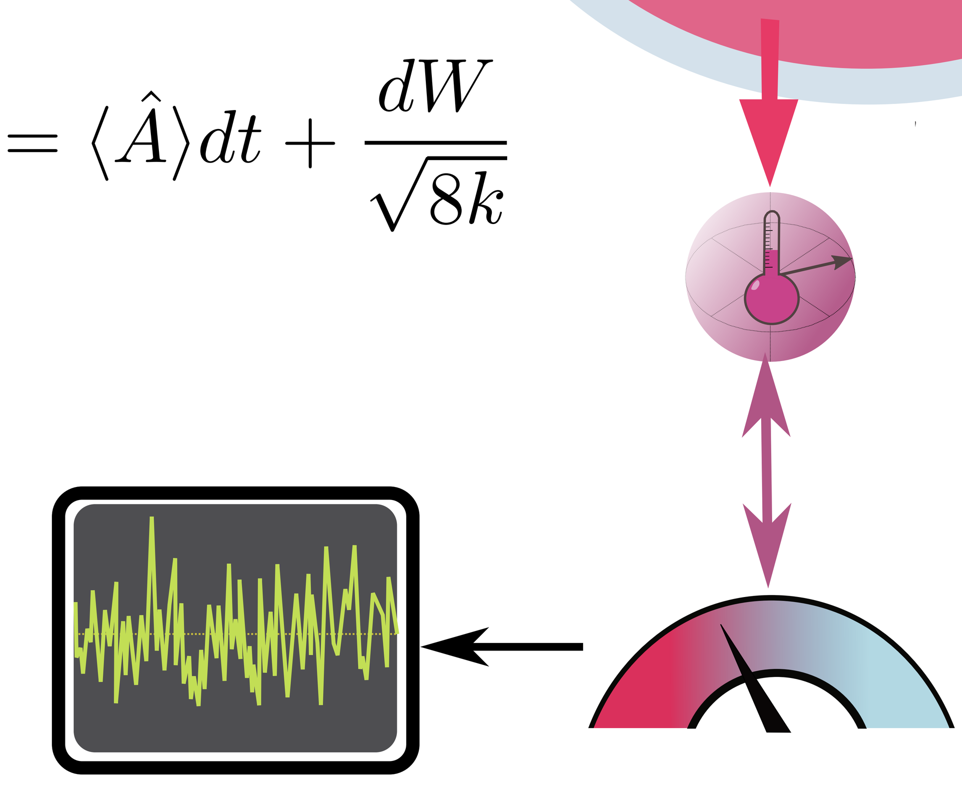
Continuous qubit thermometry

- Information gain tends to zero as measurement time decreases
- Incremental measurement signal: $dr = \langle \hat{A} \rangle dt + \frac{dW}{\sqrt{8k}}$
- Gasussian POWMs

$$M = \left(\frac{8k}{2\pi dt}\right)^{\frac{1}{4}} e^{\frac{-8k(dr - \hat{A}dt)^2}{4dt}}$$

- Additional terms in Master equation due to measurement

$$d\rho = L(\rho)dt - k[\hat{A}[\hat{A},\rho]]dt + \sqrt{2k}(\hat{A}\rho + \rho\hat{A} - 2\langle\hat{A}\rangle\rho)dW$$



Kushner-Stratonovich Equation

Use Bayes Rule to model time evolution of probability distribution

Evolution due to a single measurement

$$\delta P(T) = P(T|dr) - P(T)$$

Kushner-Stratonovich equation

$$dP(T) = 8k(\langle\hat{A}\rangle - \langle\overline{\hat{A}}\rangle)(dr - \langle\overline{\hat{A}}\rangle dt)P(T)$$

Very costly computation since the state at all temperatures must be simulated → This and noisy trajectories make optimisation difficult

Continuous monitoring and adaptive strategies

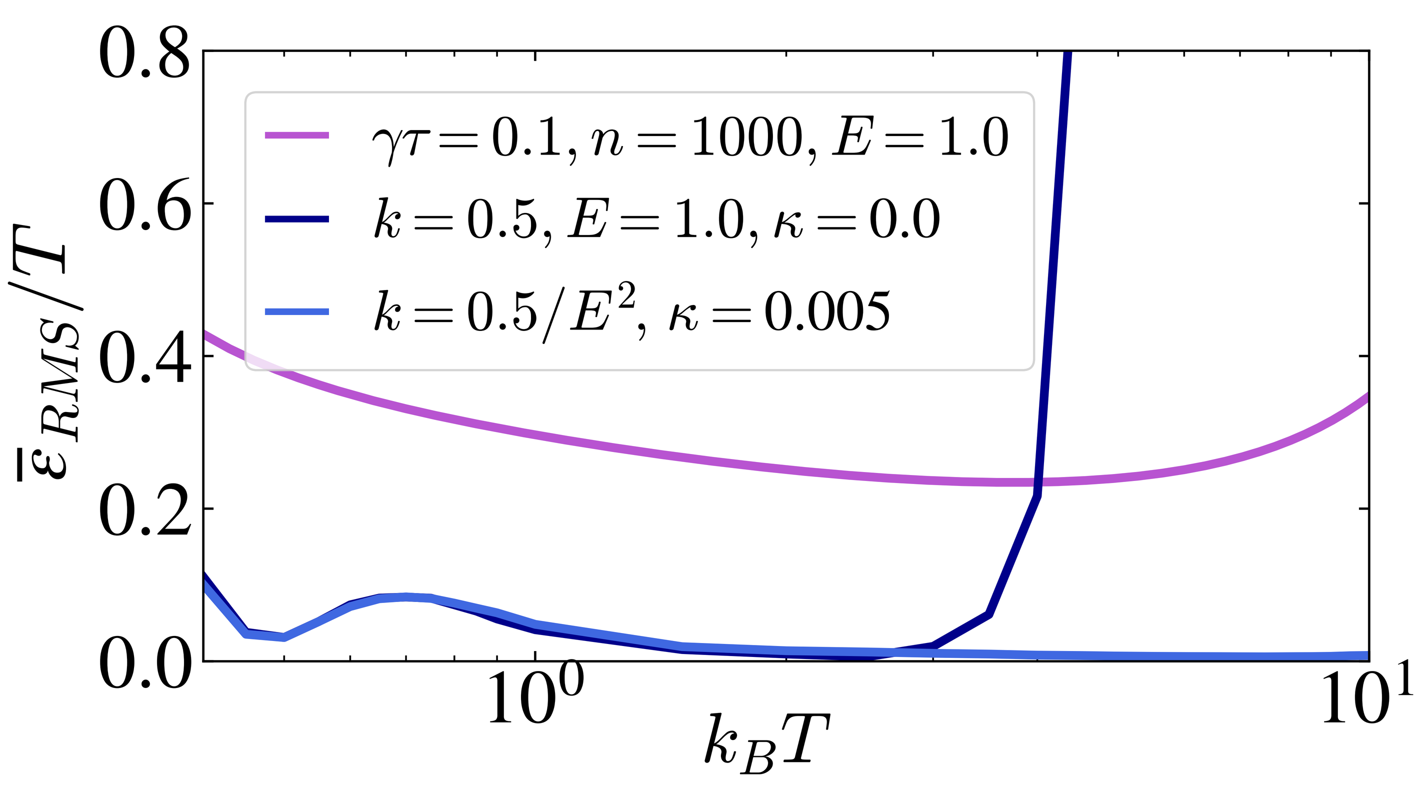
Non-Markovian Feedback:

- Hamiltonian changes with the average temperature

$$\frac{dH}{dt} = -\kappa H_0 + \kappa H_{\mathrm{targ}}$$

$$E_{\mathrm{targ}} \propto \frac{T_{\mathrm{average}}}{T_{\mathrm{optimal}}}$$

- The mesurement strength needs to be changed in proportion to the Hamiltonian!
- Optimal measurement strength and sensitivity range should still be found.



Continuous measurement beats collision model in same time → Adaptively changing the gap improves accuracy especially for high temperatures

S. Seah et. al. Phys. Rev. Lett. 123 180602 (2019)
Jason F. Ralph, Kurt Jacobs, and Charles D. Hill Phys. Rev. A 84, 052119 (2011)
J. Boeyens, S. Seah and S. Nimmrichter, Phys. Rev. A 104 (2021) 052214