bending the rules

OF LOW TEMPERATURE THERMOMETRY

with periodic driving

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want to learn about the first experimental application of quantum thermometry?

don't miss the posters by J. Glatthard and J. Rubio !

the problem

detecting temperature fluctuations precisely is very resource-intensive at low T [1].

at best, it takes $N \sim 1/T^4$ measurements to operate at any target noise-to-signal ratio $(\delta T/T)^2$ [2].

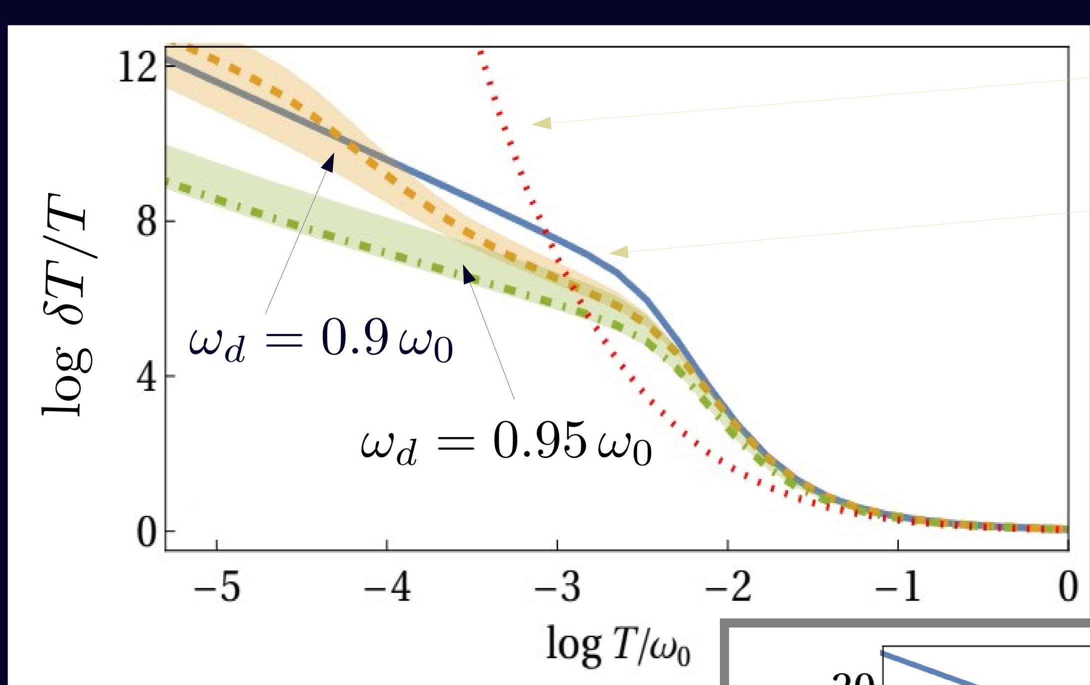
for gapped sample the scaling becomes $N \sim e^{\hbar\Omega/kT}$!!

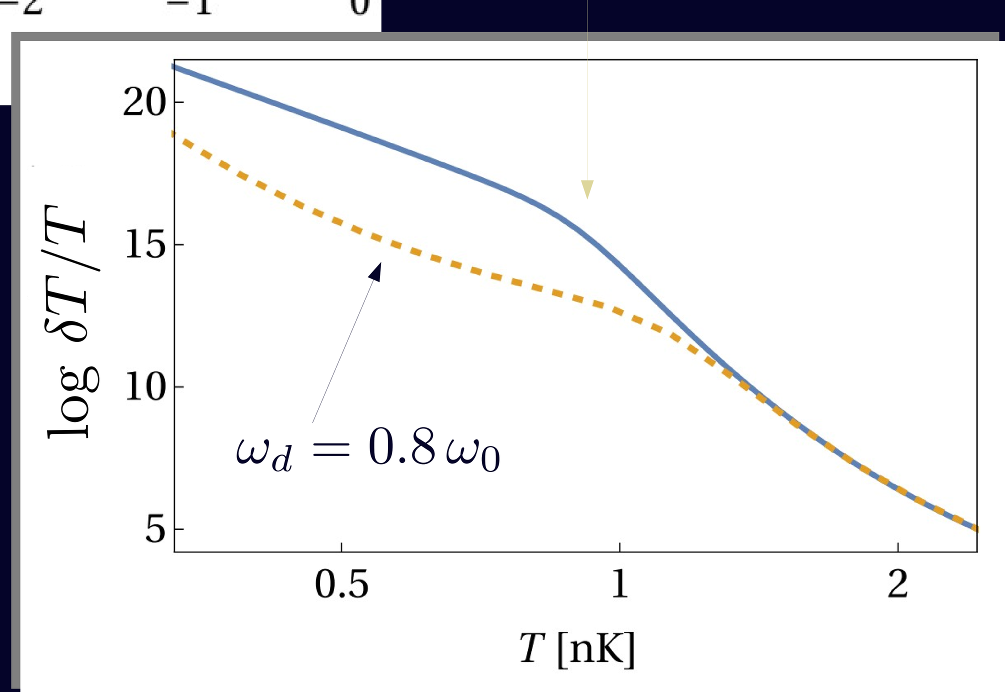
strong probe–sample coupling enhances estimation at low T, but it cannot improve the scaling [3].

the scaling is set by the properties of the sample.

one may ***bend*** the ultimate scaling laws of quantum thermometry by driving the probe periodically.

results





our results are not limited by weak-coupling or Markovian assumptions—they remain valid at arbitrarily low temperature and strong coupling [5].

- *we find improved scaling of the limit-cycle sensitivity for near-resonant driving even after time averaging (i.e., the effect is robust and does not require synchronisation between measurements and drive).*
- *we apply our model to an Yb impurity in an ultracold gas of K with a large condensed fraction [6], and find that periodic driving enables substantial sensitivity enhancement at sub-nK temperatures.*
- *the sample heating from drive-induced dissipation is negligible at weak driving [$\mathcal{O}(v^4)$] when $\omega_d \to \omega_0$ which is where the scaling advantage emerges.*

our approach

model

$$\boldsymbol{H}_S = \frac{1}{2}\omega^2(t)\boldsymbol{x}^2 + \frac{1}{2}\boldsymbol{p}^2$$

$$\omega^2(t) = \omega_0^2 + v \sin\omega_d t$$

particle in a periodically modulated harmonic potential...

$$\boldsymbol{H}_I = \boldsymbol{x}\sum \mu g_\mu \boldsymbol{x}_\mu$$

$$\boldsymbol{H}_B = \sum_\mu \frac{1}{2}\omega_\mu^2 m_\mu \boldsymbol{x}_\mu^2 + \frac{\boldsymbol{p}_\mu^2}{2m_\mu}$$

...linearly coupled to a linear bosonic bath.

quantum Langevin equation (QLE)

$$\ddot{\boldsymbol{x}} + \left(\omega^2(t) + \omega_R^2\right)\boldsymbol{x} - \int_0^t \chi(t-\tau)\,\boldsymbol{x}(\tau) = \boldsymbol{F}(t)$$

reorganisation energy · *dissipation kernel* · *quantum noise*

Green's function of the QLE [4]

$$g(t,t') = \frac{1}{2\pi}\sum_{k=-\infty}^{\infty}\int_{-\infty}^{\infty} a_k(\omega)e^{i\omega(t-t')}e^{ik\omega_d t}\,d\omega$$

we formally expand these in the driving strength v

'limit-cycle' probe state $\varrho_T(t)$

$$\overline{\varrho}_T := \int_0^{\frac{2\pi}{\omega_d}} \varrho_T(t)\,dt$$

instantaneous limit-cycle to any order in v

limit cycle must be averaged if measurements not synchronised with drive

thermal sensitivity

Cramér–Rao bound: *tight if estimator is locally unbiased*

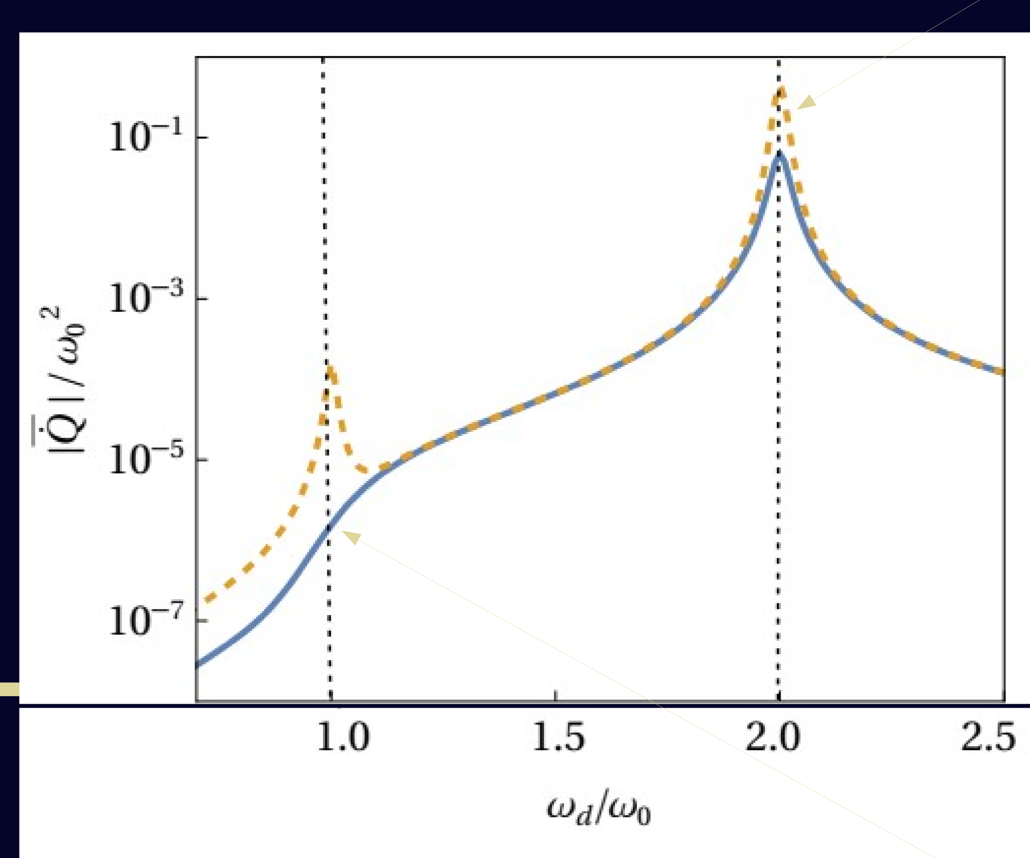
$$\delta T \geq [N\,\mathcal{F}_T(\varrho)]^{-1/2}$$

quantum Fisher information (QFI)

difficult to calculate for a non-Gaussian state like ϱ_T

$$F_T(\boldsymbol{x}^2, \overline{\varrho}_T) \leq \mathcal{F}_T(\overline{\varrho}_T) \leq \overline{\mathcal{F}_T[\varrho_T(t)]}$$

improved scaling can still be demonstrated by sandwiching the QFI



references

[1] Karen V. Hovhannisyan and Luis A. Correa. Phys. Rev. B 98, 045101 (2018). [2] Patrick P. Potts, Jonatan Bohr Brask, and Nicolas Brunner, Quantum 3, 161 (2019). [3] Luis A. Correa *et al.*, Phys. Rev. A 96, 062103 (2017). [4] Nahuel Freitas and Juan Pablo Paz, Phys. Rev. E 95, 012146 (2017). [5] Victor Mukherjee *et al.*, Commun. Phys. 2, 162 (2019). [6] Mohammad Mehboudi *et al.*, Phys. Rev. Lett.,122, 030403 (2019).