WE-HERAEUS SEMINAR—BAD-HONNEF—10 APRIL 2017

LOW-TEMPERATURE THERMOMETRY

ENHANCED

BY *STRONG* COUPLING

luis a. correa

The University of Nottingham

luis a. correa

mohammad mehboudi

anna sanpera

martí perarnau

karen hovhannisyan

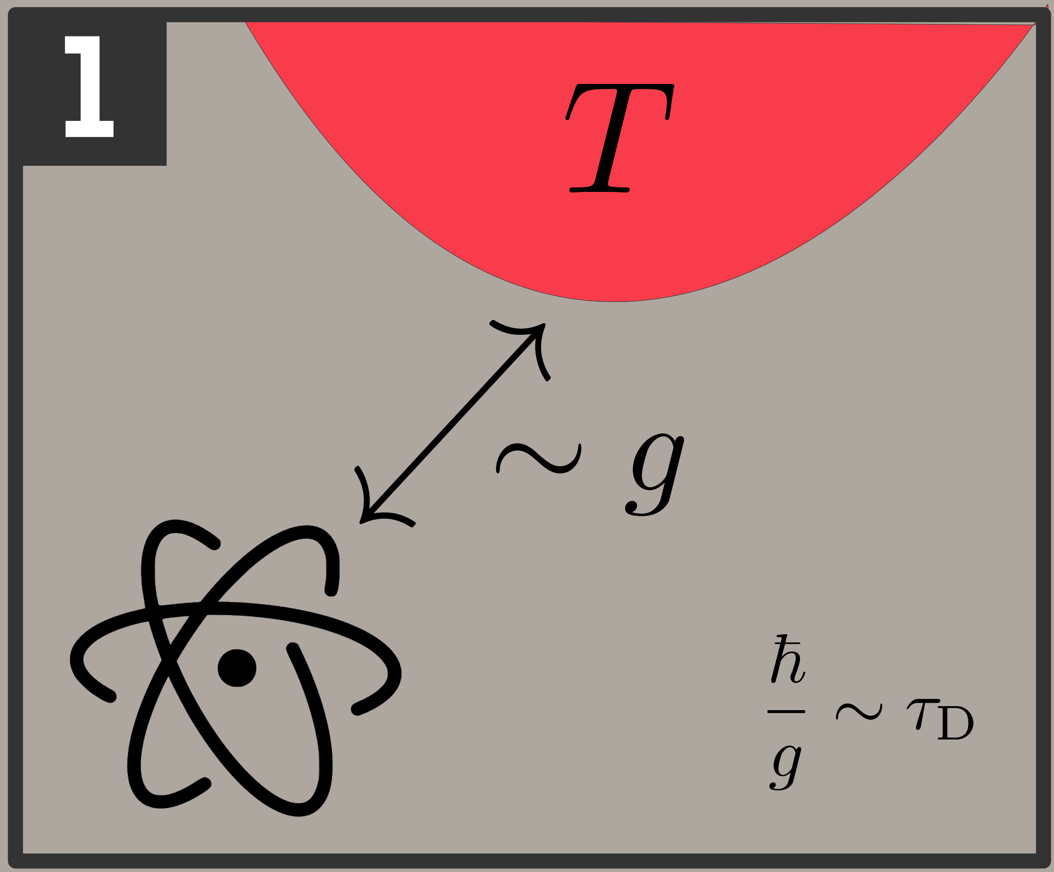
senaida hernández

Universitat Autònoma de Barcelona

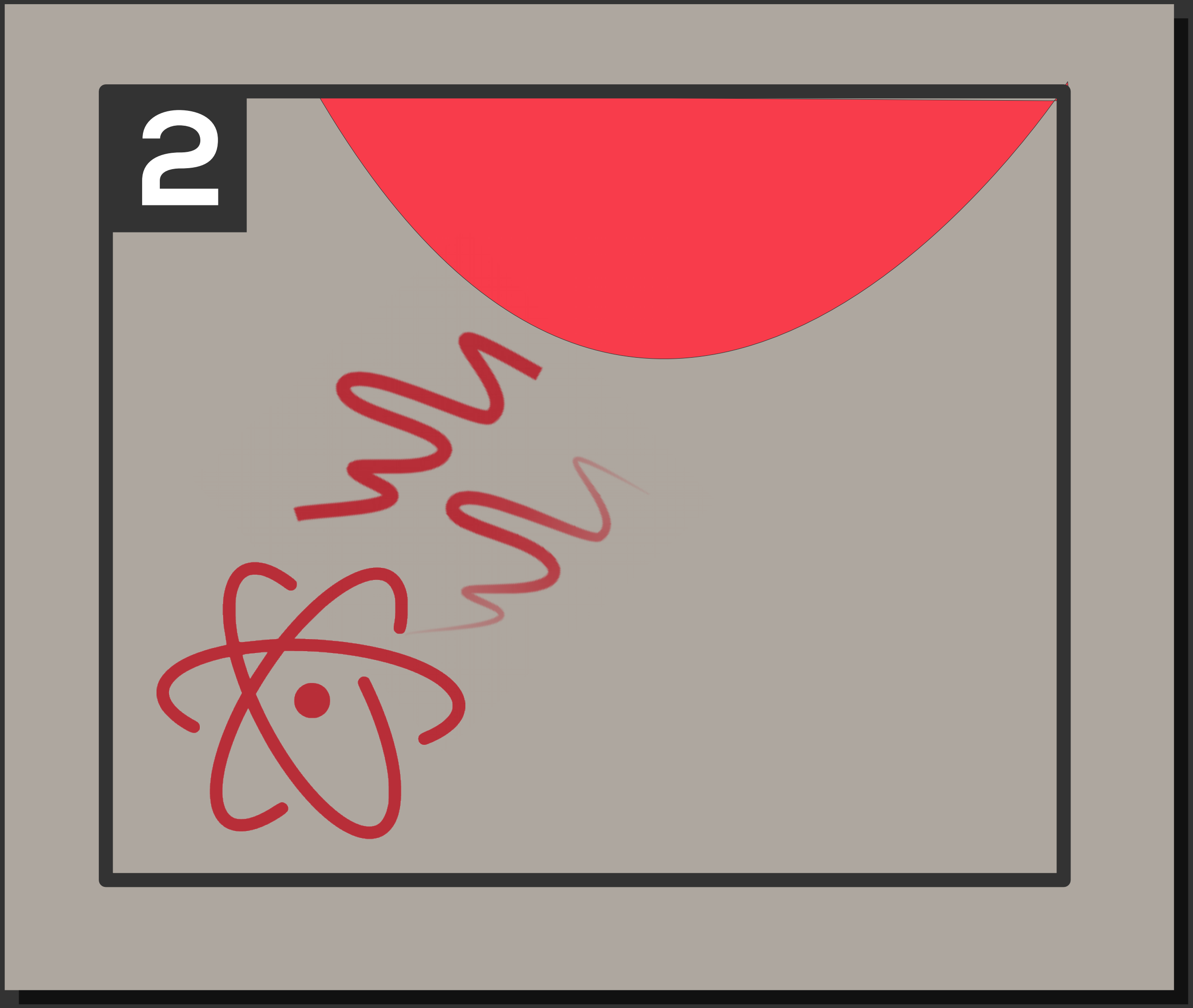
The Institute of Photonic Sciences

ESTIMATING TEMPERATURE

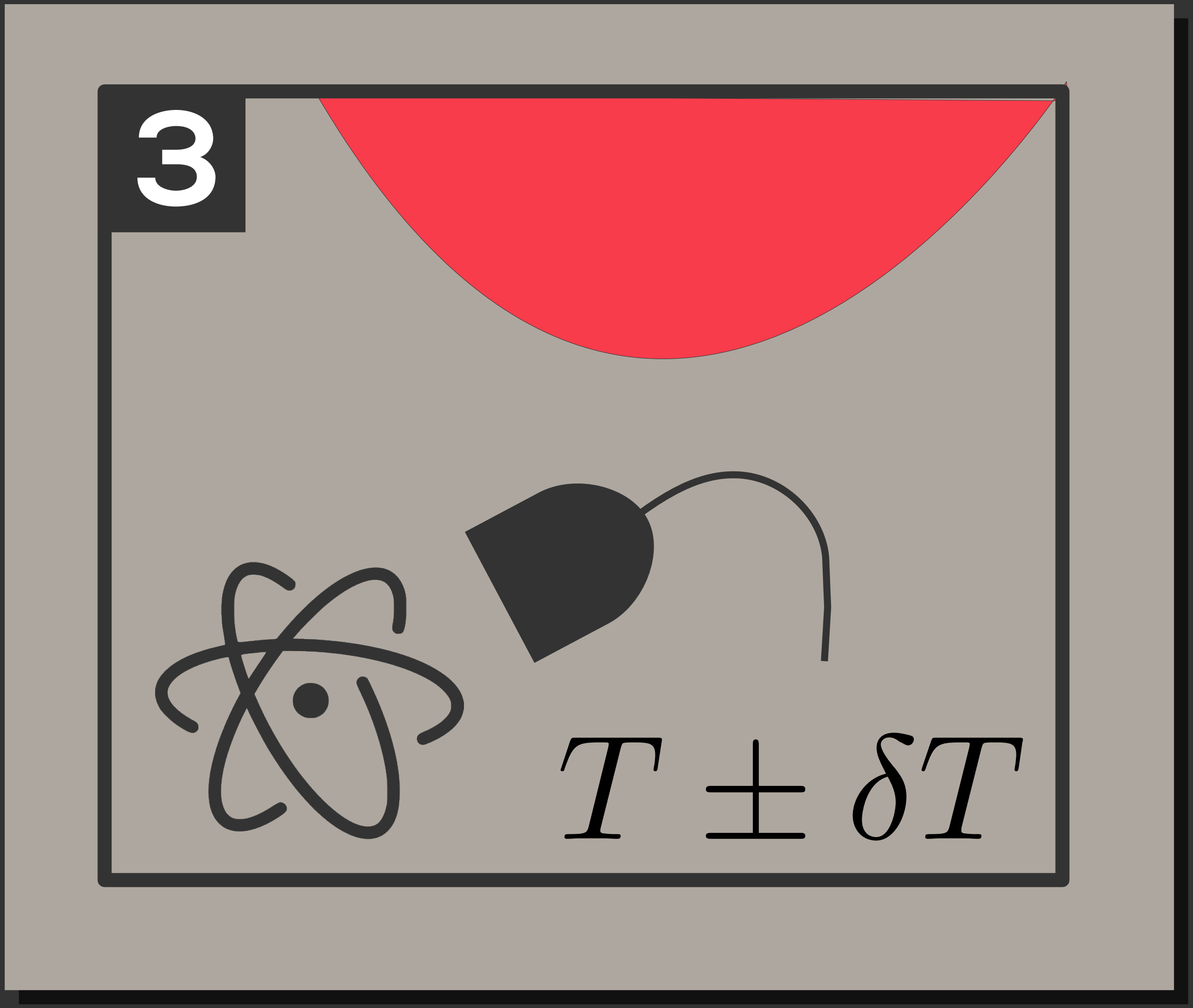
ESTIMATING TEMPERATURE



ESTIMATING TEMPERATURE



ESTIMATING TEMPERATURE



ESTIMATING TEMPERATURE

$$\delta T \geq \frac{1}{\sqrt{N \mathcal{F}_T}}$$

number of repetitions

quantum fisher information

ESTIMATING TEMPERATURE

$$\delta T \geq \frac{1}{\sqrt{N F_T(\hat{O})}}$$

classical
fisher
information

$$\mathcal{F}_T \geq F_T(\hat{O}) \geq \frac{|\partial_T \langle \hat{O} \rangle|^2}{\Delta^2 \hat{O}}$$

OUTLINE

- [ ] motivation: low-T thermometry can be *exponentially* inefficient

- [ ] the model: the caldeira-legget model (CL)

- [ ] results:

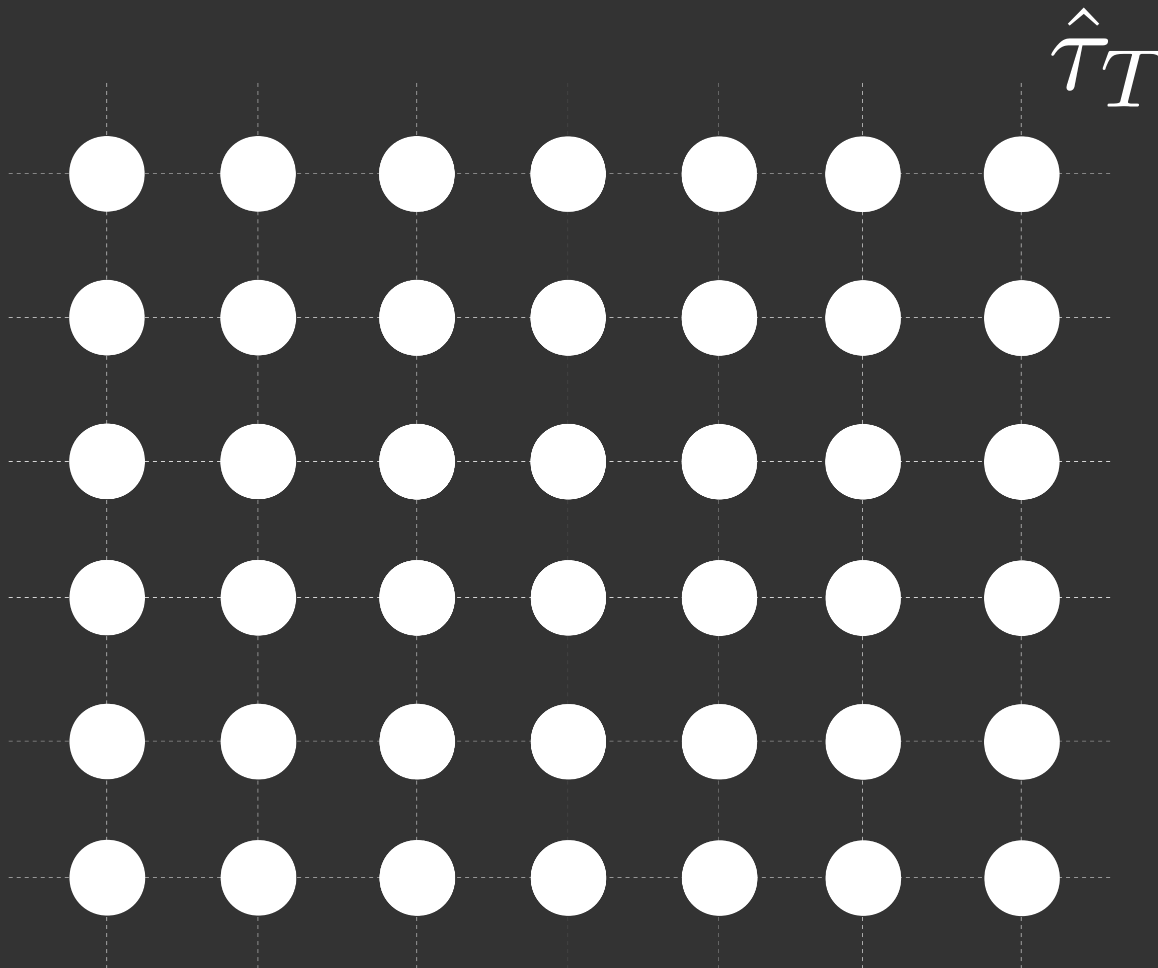
  #1 strong coupling enhances thermal sensitivity at low T

  #2 thermometry from the variance of the quadratures is quasi optimal

  #3 the spectral density matters

- [ ] physical intuition: the lowest-frequency normal modes are the key

MOTIVATION



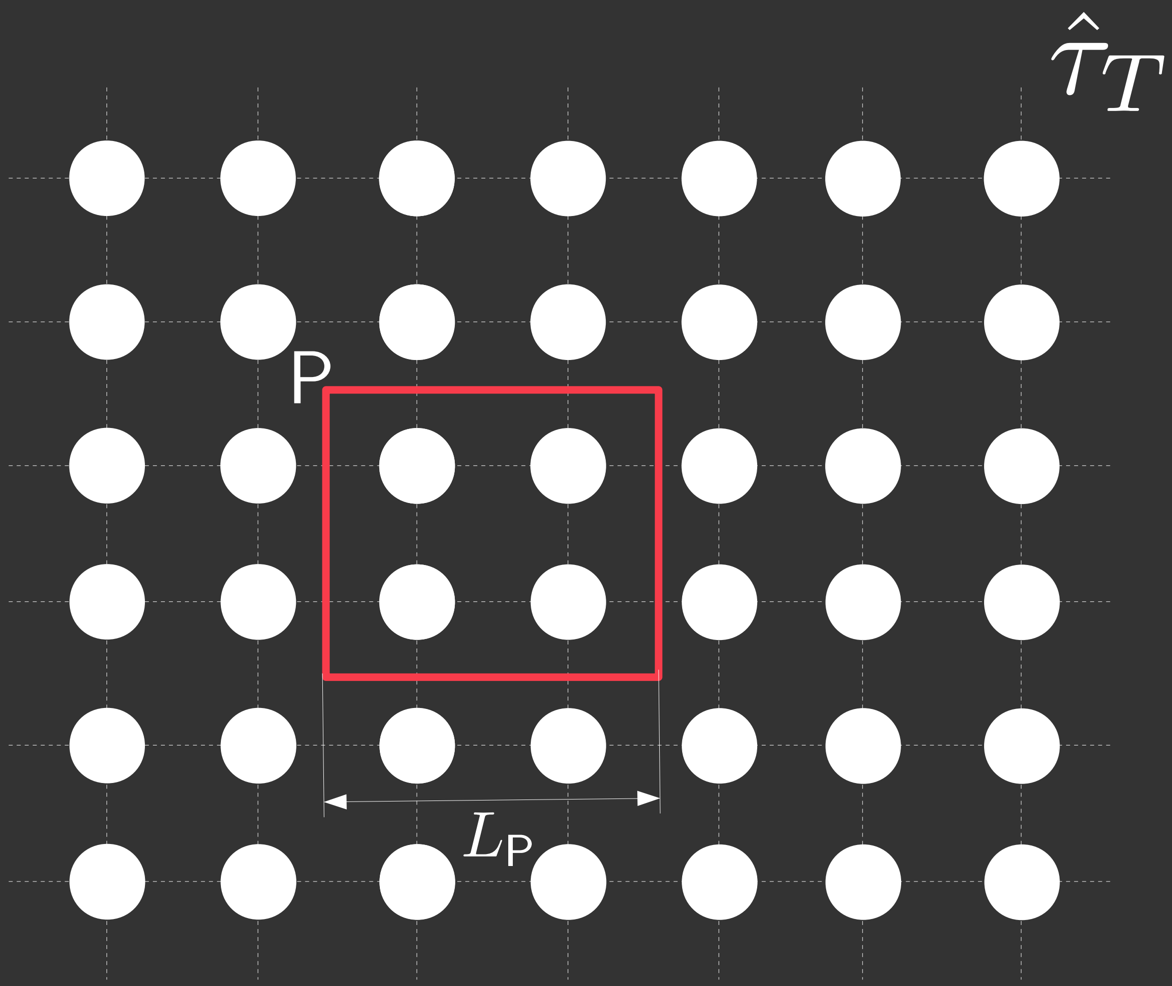
→ suficiently large

→ translationally invariant

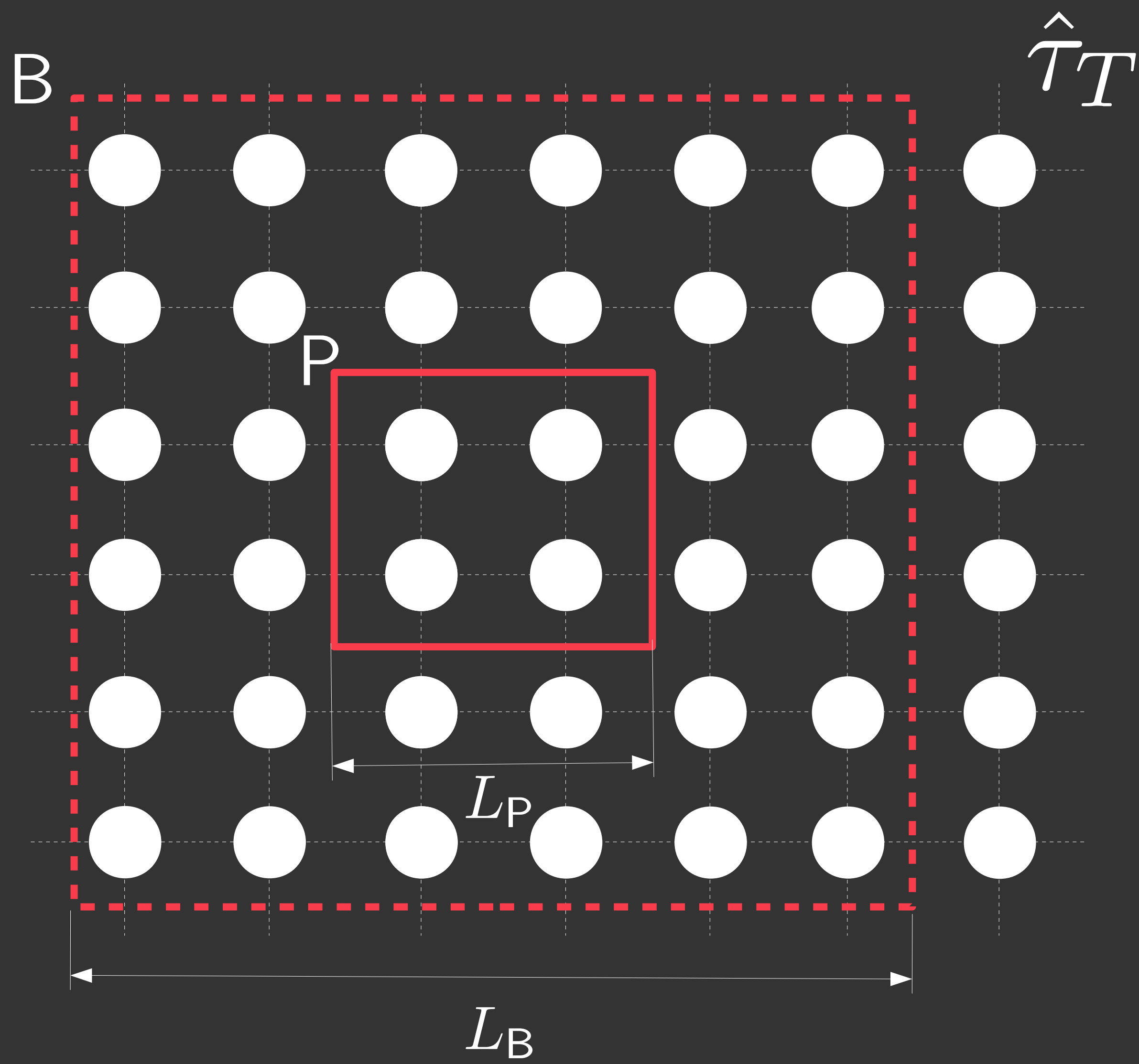
→ short range interactions

→ away from criticality

MOTIVATION



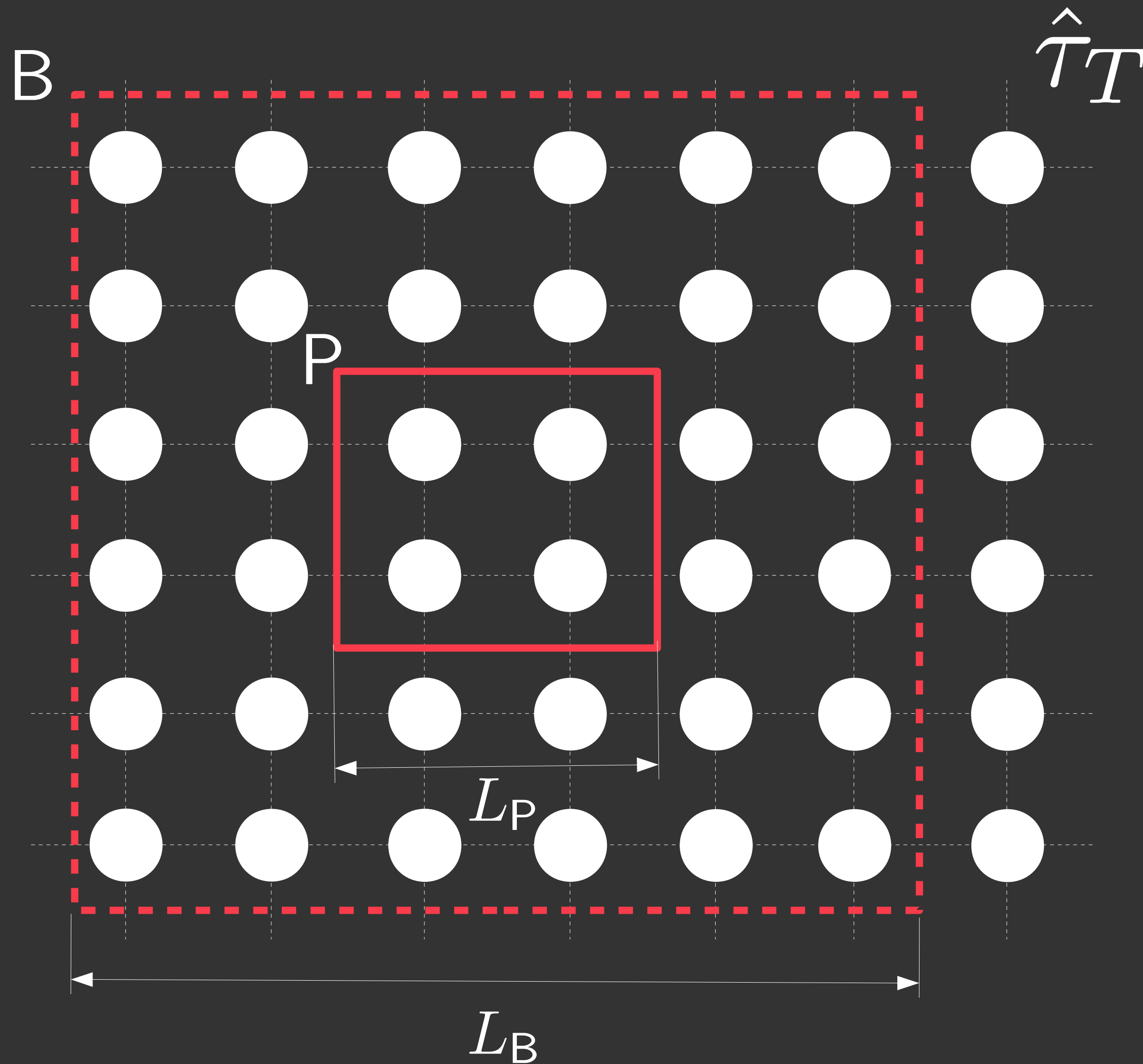
MOTIVATION



$$\mathrm{tr}_\mathsf{B}\,\hat{\tau}_T(L_\mathsf{B}) \equiv \hat{\varrho}_\mathsf{P}(L_\mathsf{B})$$

$$\mathrm{tr}_\mathsf{B}\,\hat{\tau}_T(\infty) = \hat{\varrho}_\mathsf{P}$$

MOTIVATION



$$\mathrm{tr}_{\mathsf{B}}\, \hat{\tau}_T(L_{\mathsf{B}}) \equiv \hat{\varrho}_{\mathsf{P}}(L_{\mathsf{B}})$$

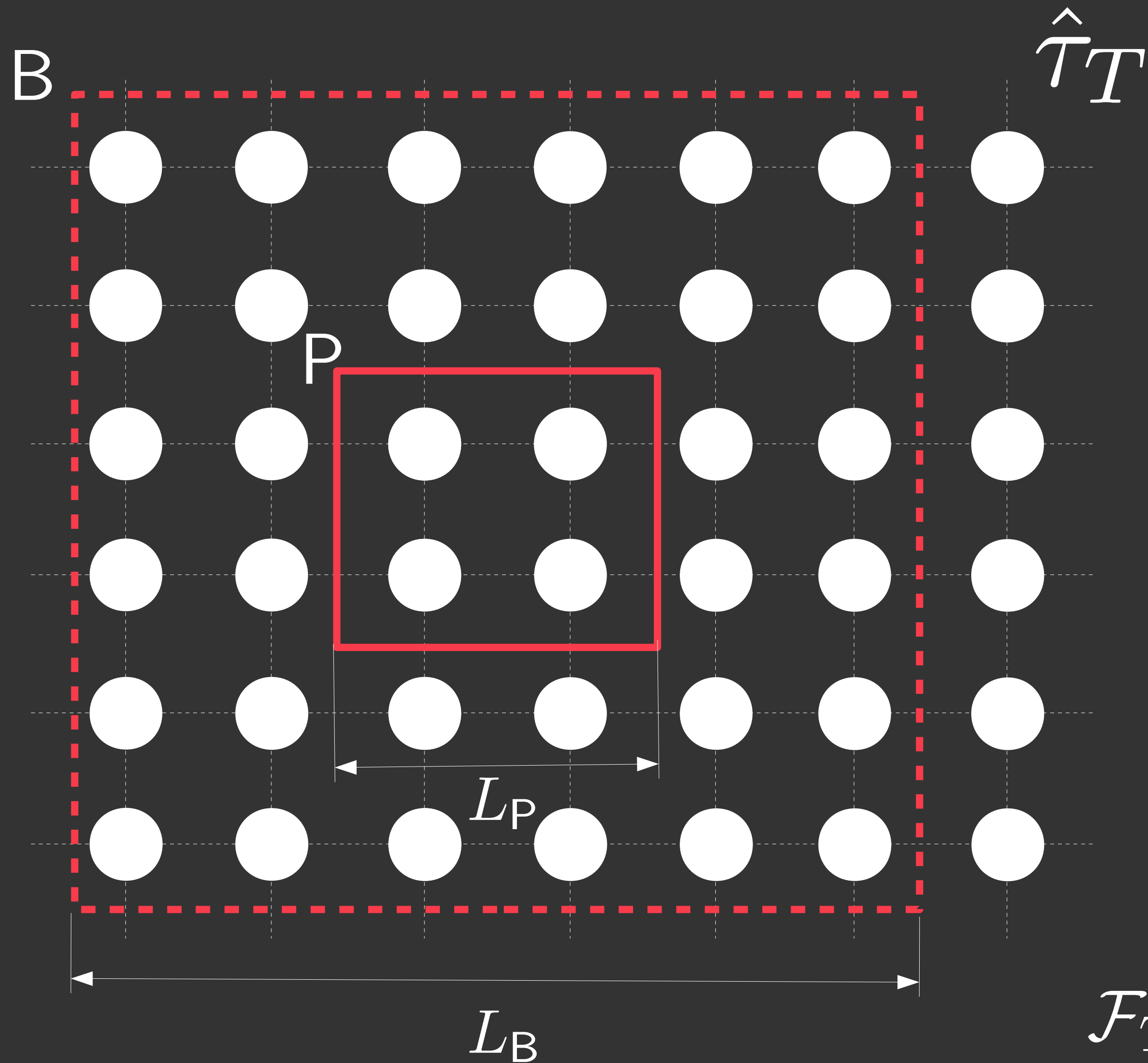
$$\mathrm{tr}_{\mathsf{B}}\, \hat{\tau}_T(\infty) = \hat{\varrho}_{\mathsf{P}}$$

$$\mathbb{F}(\hat{\varrho}_{\mathsf{P}}, \hat{\varrho}_{\mathsf{P}}(L_{\mathsf{B}})) \\ = 1 - \mathcal{O}(1) e^{-L/\xi}$$

phys. rev. x 4, 031019 (2014)

new j. phys. 17, 085007 (2015)

MOTIVATION



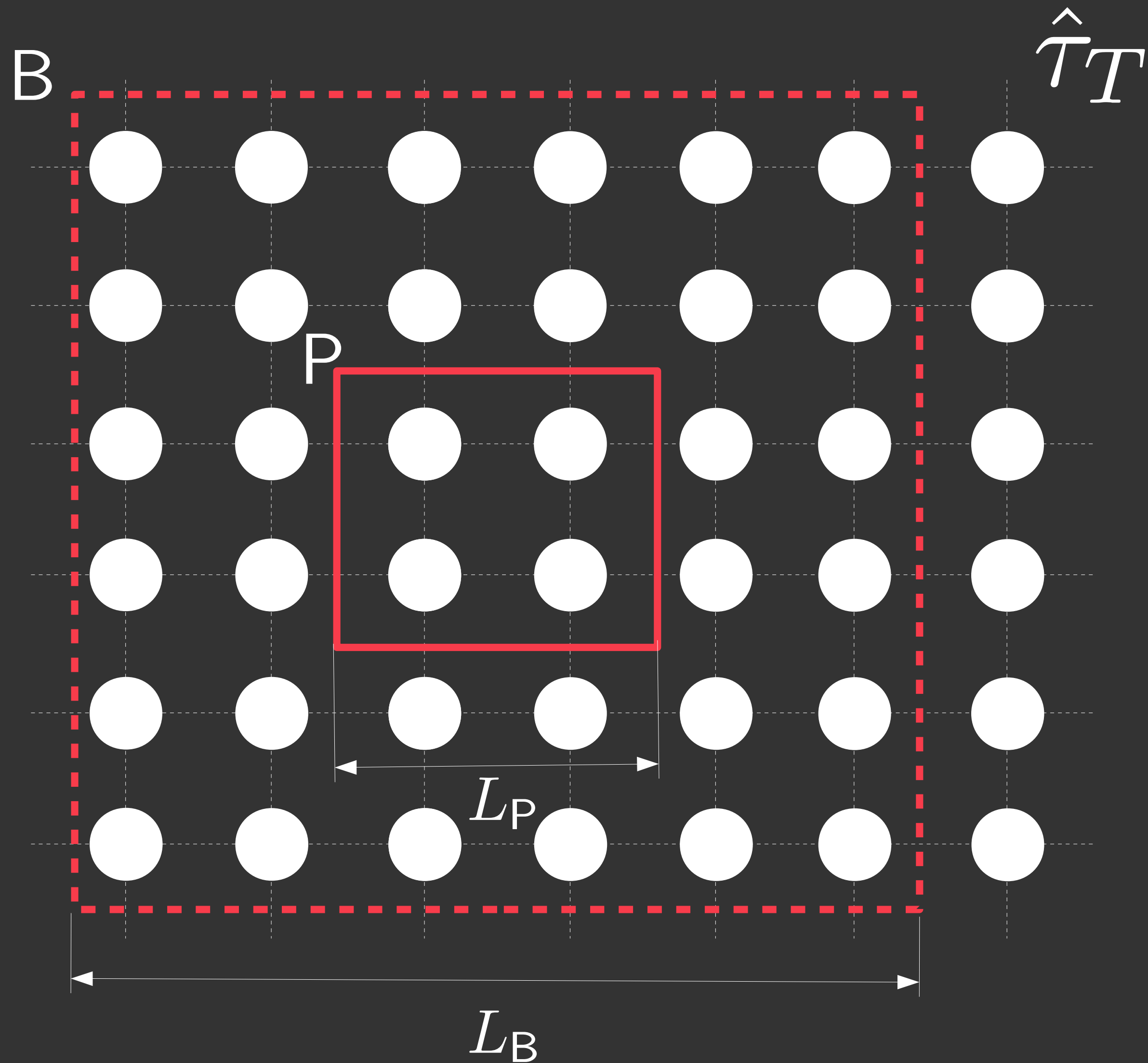
$$\mathrm{tr}_{\mathsf{B}}\, \hat{\tau}_T(L_{\mathsf{B}}) \equiv \hat{\varrho}_{\mathsf{P}}(L_{\mathsf{B}})$$

$$\mathrm{tr}_{\mathsf{B}}\, \hat{\tau}_T(\infty) = \hat{\varrho}_{\mathsf{P}}$$

$$\mathbb{F}(\hat{\varrho}_{\mathsf{P}}, \hat{\varrho}_{\mathsf{P}}(L_{\mathsf{B}})) = 1 - \mathcal{O}(1)e^{-L/\xi}$$

$$\mathcal{F}_T = -2\frac{\partial^2}{\partial\delta^2}\mathbb{F}(\hat{\varrho}_T, \hat{\varrho}_{T+\delta})$$

MOTIVATION



small parts of large systems* become insensitive to the global temperature *exponentially* with 1/T

$$\mathcal{F}_T \leq \mathcal{O}(1)(\Delta/T)^5\, e^{-\Delta/T} \qquad \Delta/T \gg 1$$

OUTLINE

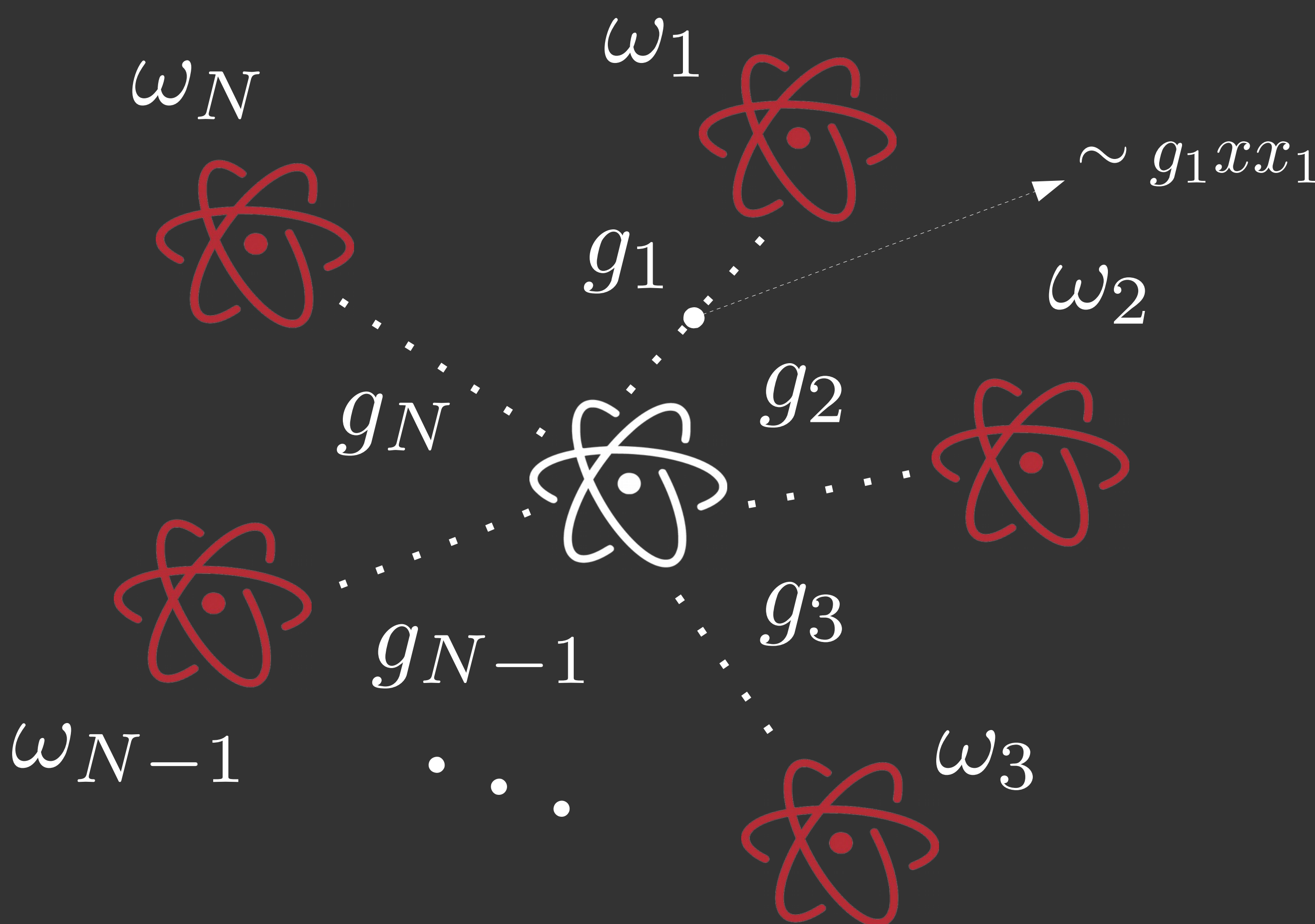
- [x] <u>motivation</u>: low-T thermometry can be *exponentially* inefficient
- [ ] <u>the model</u>: the caldeira-legget model (CL)
- [ ] <u>results</u>:

  #1 strong coupling enhances thermal sensitivity at low T

  #2 thermometry from the variance of the quadratures is quasi optimal

  #3 the spectral density matters
- [ ] <u>physical intuition</u>: the lowest-frequency normal modes are the key

THE MODEL



$$J(\omega) := \pi \sum_{\mu} \frac{g_\mu^2}{2 m_\mu \omega_\mu} \delta(\omega - \omega_\mu)$$

THE MODEL

$$\boxed{\ddot{x}(t) + \tilde{\omega}_0^2 x(t)^2 - x(t) \star \chi(t) = F(t)}$$

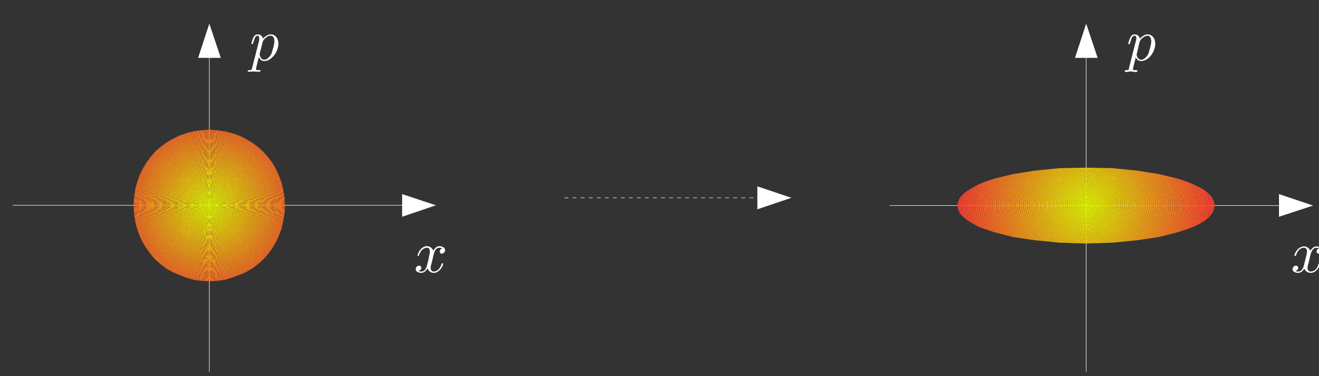
quantum langevin equation (QLE)

the steady state of the QLE can be obtained *exactly* provided that:

→ probe and sample start *uncorrelated*

→ the sample starts at *thermal equilibrium*

→ the overall probe-sample Hamiltonian is *quadratic*



THE MODEL

$$\ddot{x}(t) + \tilde{\omega}_0^2 x(t)^2 - x(t) \star \chi(t) = F(t)$$

$$\mathcal{F}_T = -2 \frac{\partial^2}{\partial \delta^2} \mathbb{F}(\hat{\varrho}_T, \hat{\varrho}_{T+\delta})$$

OUTLINE

☑ <u>motivation</u>: low-T thermometry can be *exponentially* inefficient

☑ <u>the model</u>: the caldeira-legget model (CL)

☐ <u>results</u>:

#1 strong coupling enhances thermal sensitivity at low T

#2 thermometry from the variance of the quadratures is quasi optimal

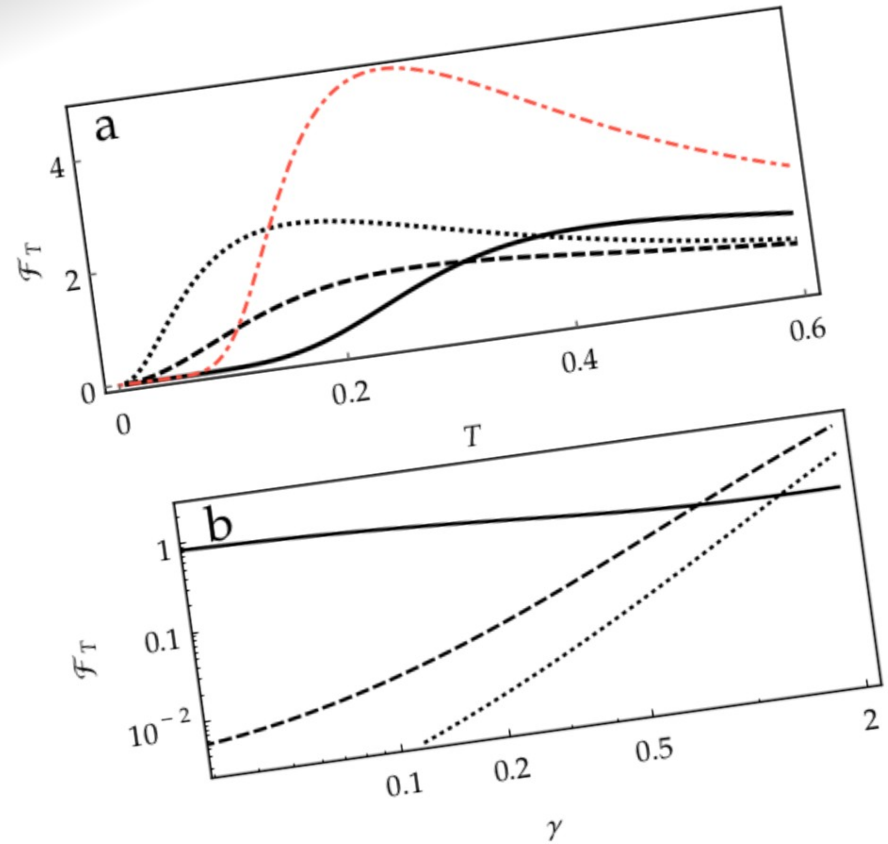
#3 the spectral density matters

☐ <u>physical intuition</u>: the lowest-frequency normal modes are the key

RESULTS

#1

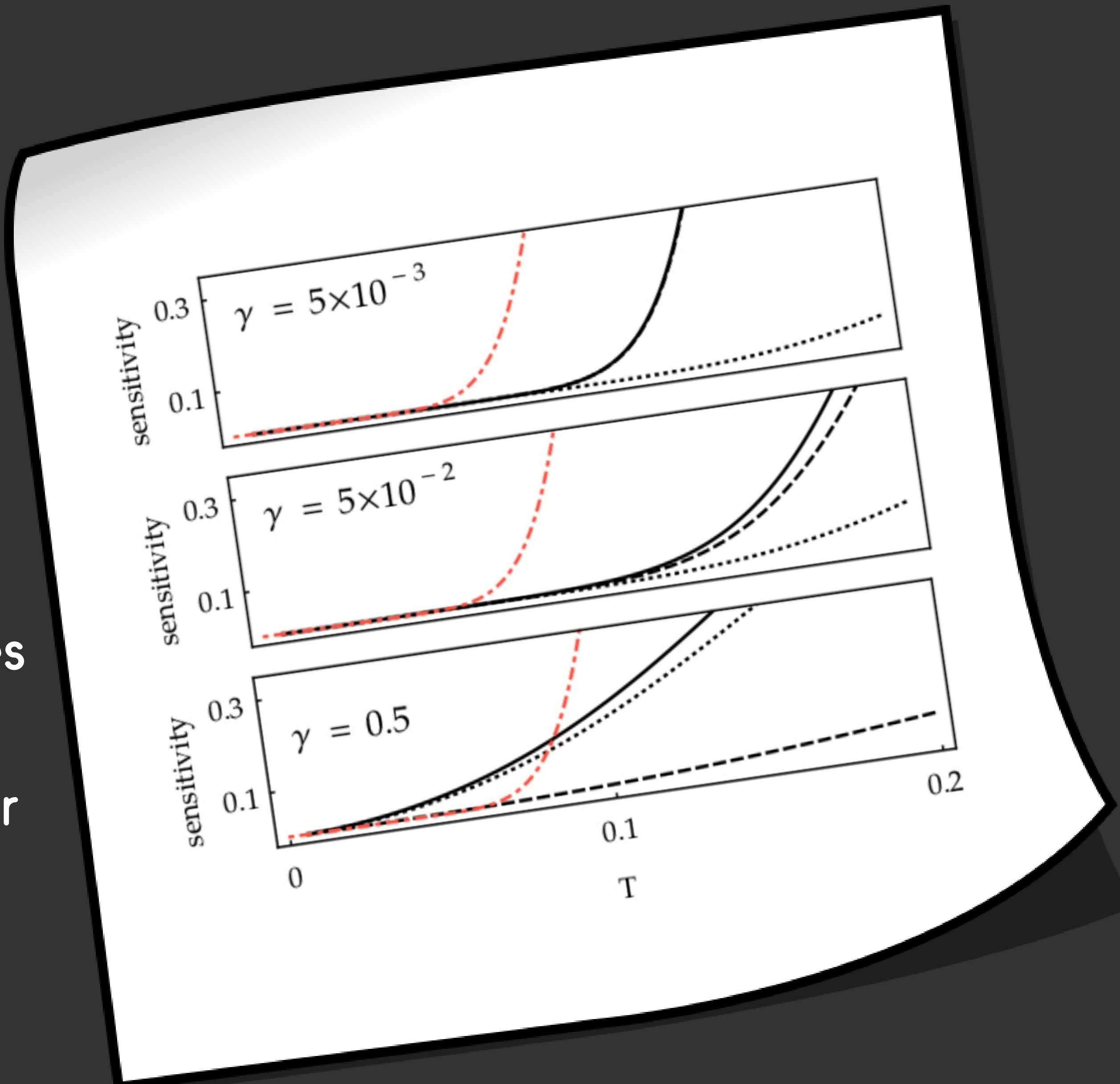
if the temperature is low enough, the thermal sensitivity *grows monotonically* with the probe-sample coupling strength.



RESULTS

#2

at sufficiently strong coupling, $\langle \hat{x}^2 \rangle$ becomes a quasi-optimal temperature estimator



RESULTS

$$J(\omega) := \pi \sum_{\mu} \frac{g_{\mu}^{2}}{2m_{\mu}\omega_{\mu}} \delta(\omega - \omega_{\mu})$$

RESULTS

$$\boxed{J_s(\omega) = \frac{\pi}{2}\gamma\,\omega^s\,\omega_c^{1-s}\,e^{-\omega/\omega_c}}$$

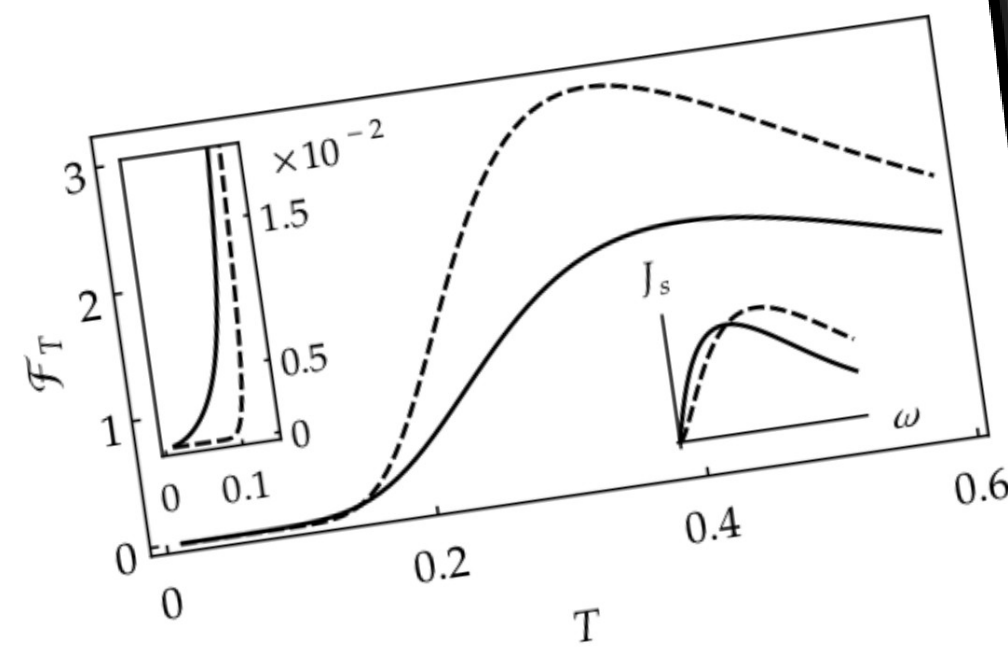
$s = 1$ → ohmic spectral density

$s > 1$ → super-ohmic spectral density

RESULTS

#3

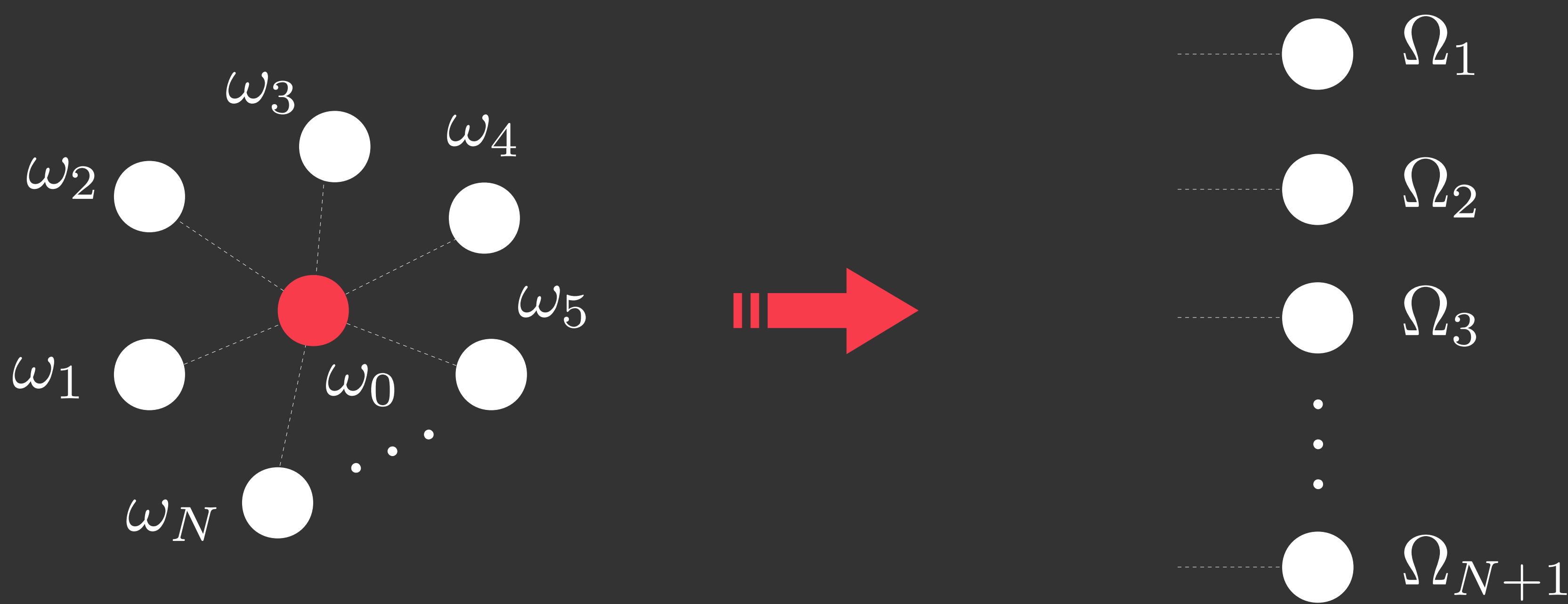
the low-temperature thermal sensitivity grows with the probe-sample coupling strength at low frequencies



OUTLINE

- [x] <u>motivation</u>: low-T thermometry can be *exponentially* inefficient
- [x] <u>the model</u>: the caldeira-legget model (CL)
- [x] <u>results</u>:
  - #1 strong coupling enhances thermal sensitivity at low T
  - #2 thermometry from the variance of the quadratures is quasi optimal
  - #3 the spectral density matters
- [ ] <u>physical intuition</u>: the lowest-frequency normal modes are the key

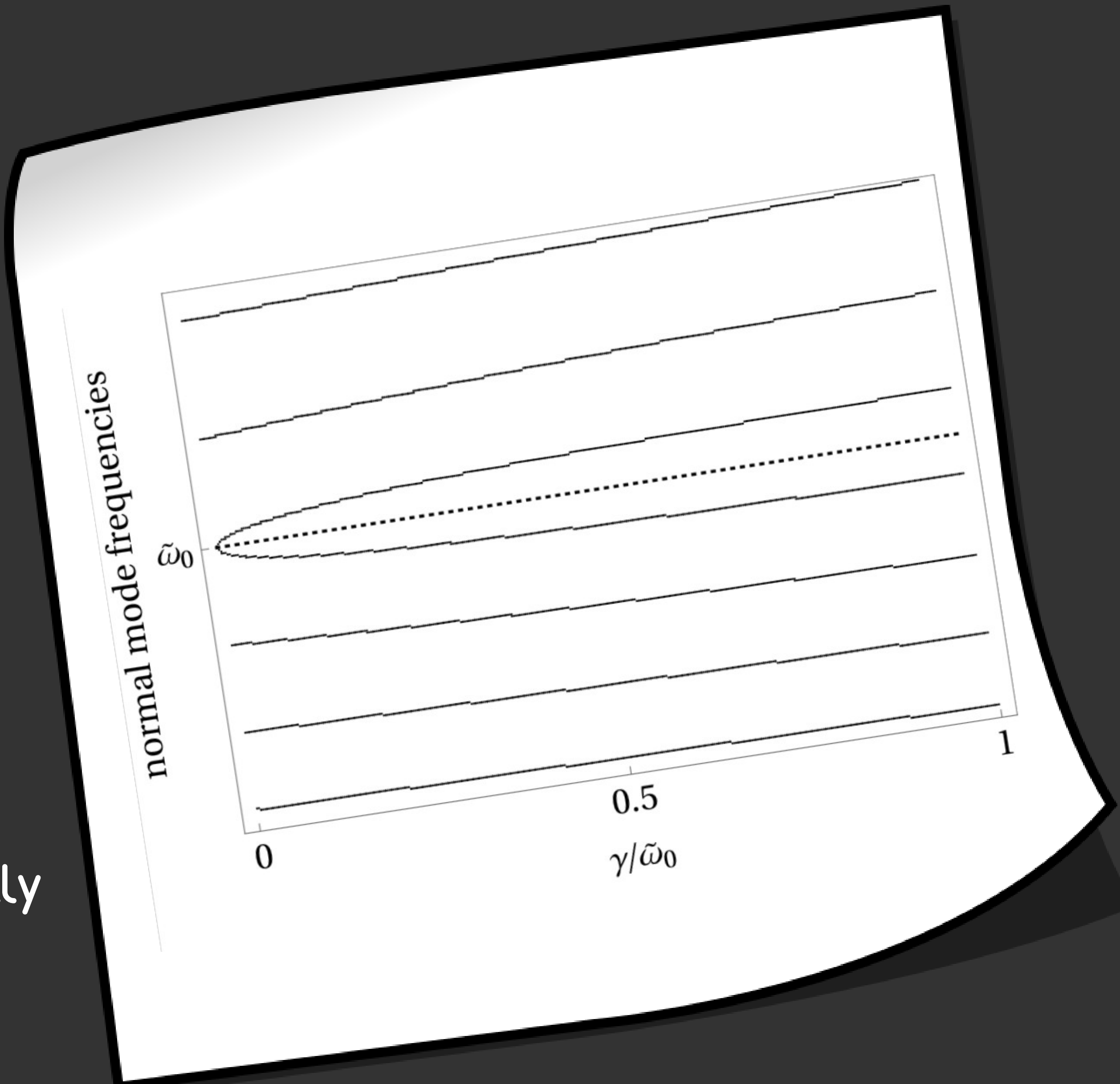
PHYSICAL INTUITION



PHYSICAL INTUITION

#4

the frequencies of the lowermost normal modes of a CL-like *"star model"* decrease monotonically with the coupling strength



OUTLINE

- ☑ <u>motivation</u>: low-T thermometry can be *exponentially* inefficient
- ☑ <u>the model</u>: the caldeira-legget model (CL)
- ☑ <u>results</u>:
  - **#1** strong coupling enhances thermal sensitivity at low T
  - **#2** thermometry from the variance of the quadratures is quasi optimal
  - **#3** the spectral density matters
- ☑ <u>physical intuition</u>: the lowest-frequency normal modes are the key

arXiv:1611.10123

thanks for your attention!