Weizmann Institute, ≈ 93

Quantum Noise & Electron-phonon coupling of a diffusive wire

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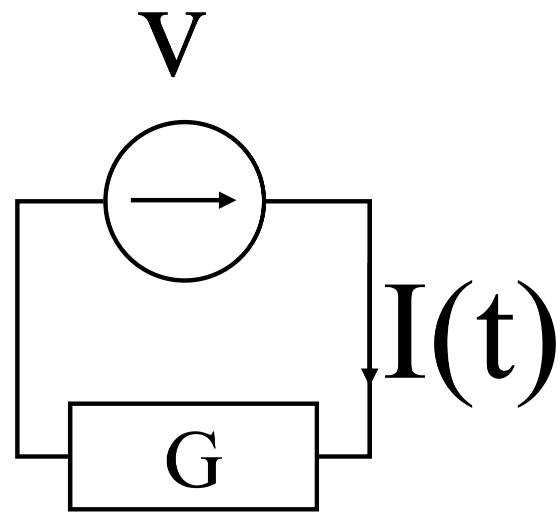
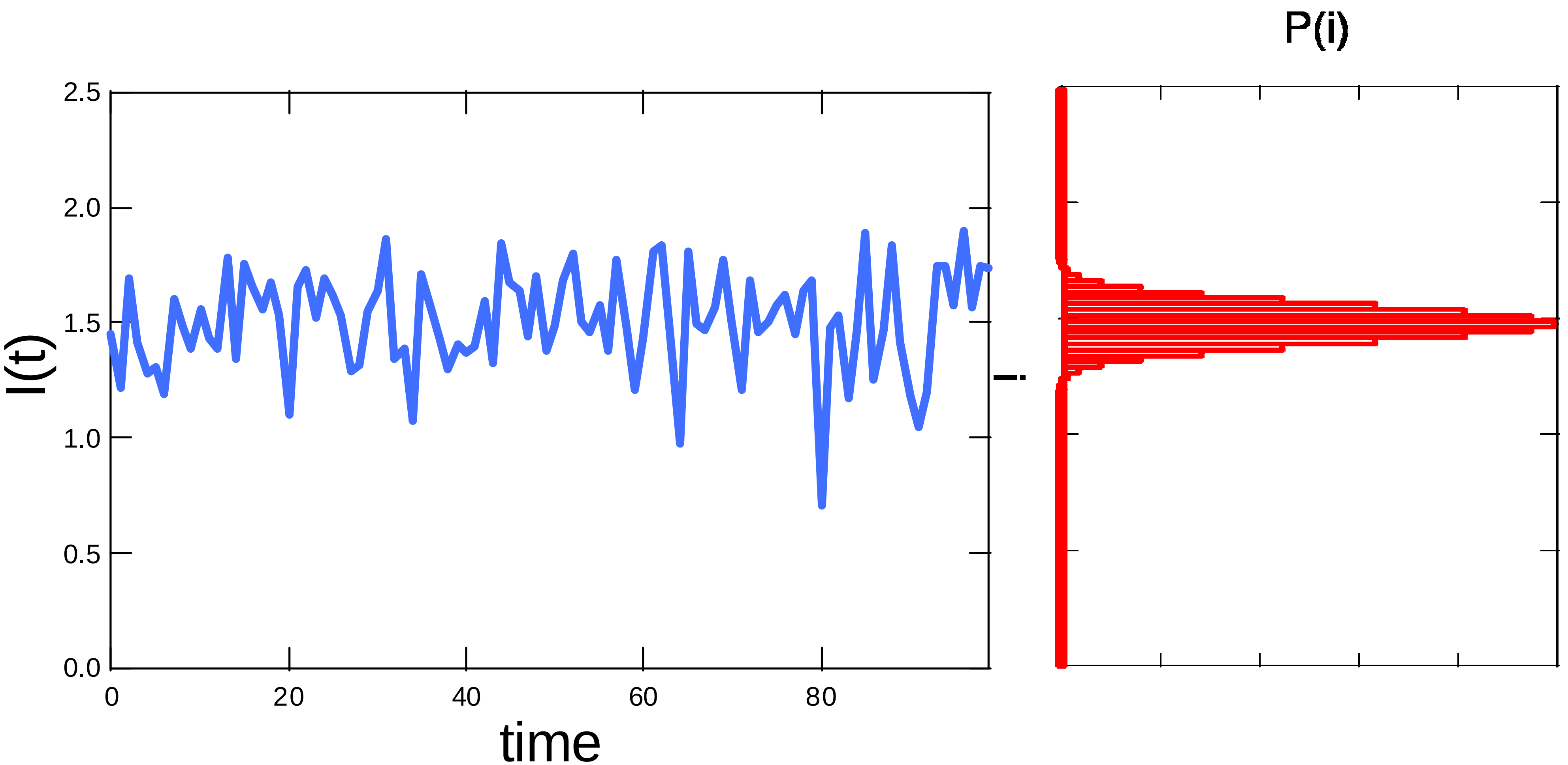
Noise: can look inside a nano-device

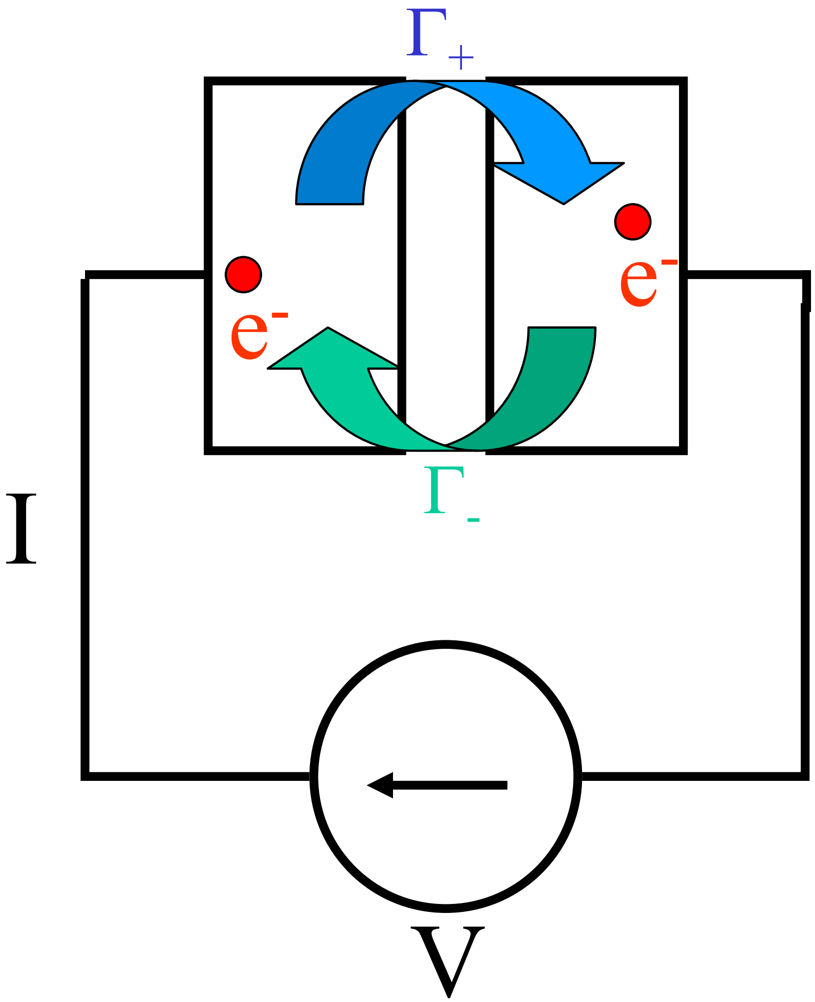
- new physics
- time scales – this work

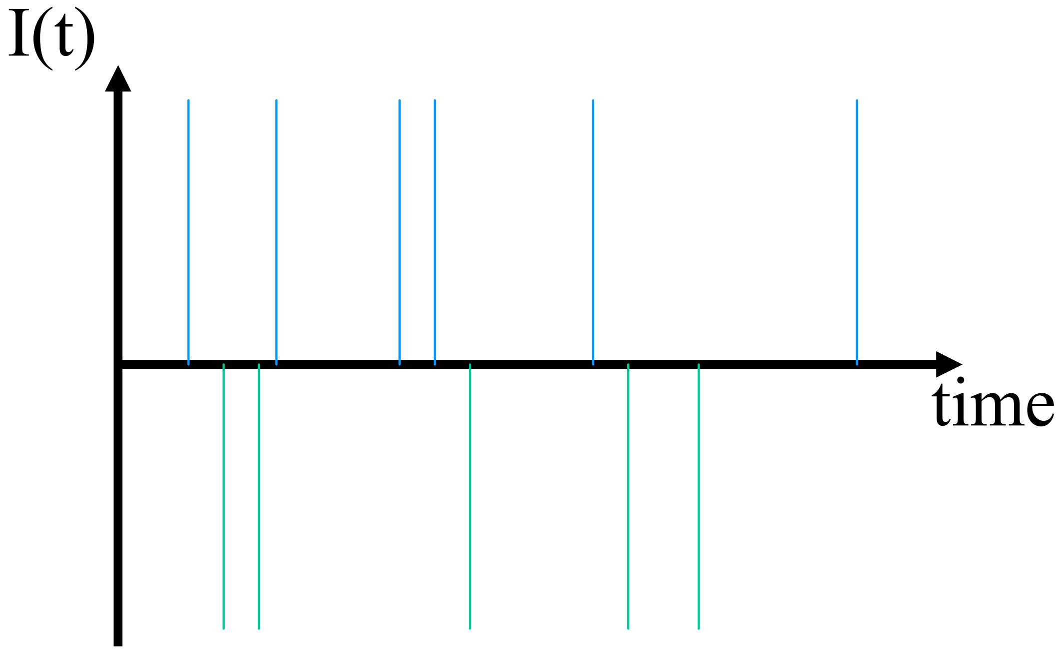
Probability distribution of the current P(i)





Current in a tunnel junction (single channel)





S_3 for a tunnel junction

$$\langle I^3 \rangle = \left(+\frac{e}{\tau}\right)^3 \Gamma_+ \tau + \left(-\frac{e}{\tau}\right)^3 \Gamma_- \tau = \frac{e^3}{\tau^3}\left(\Gamma_+ \tau - \Gamma_- \tau\right) = \frac{e^2}{\tau^2}\langle I \rangle$$

Spectral density:

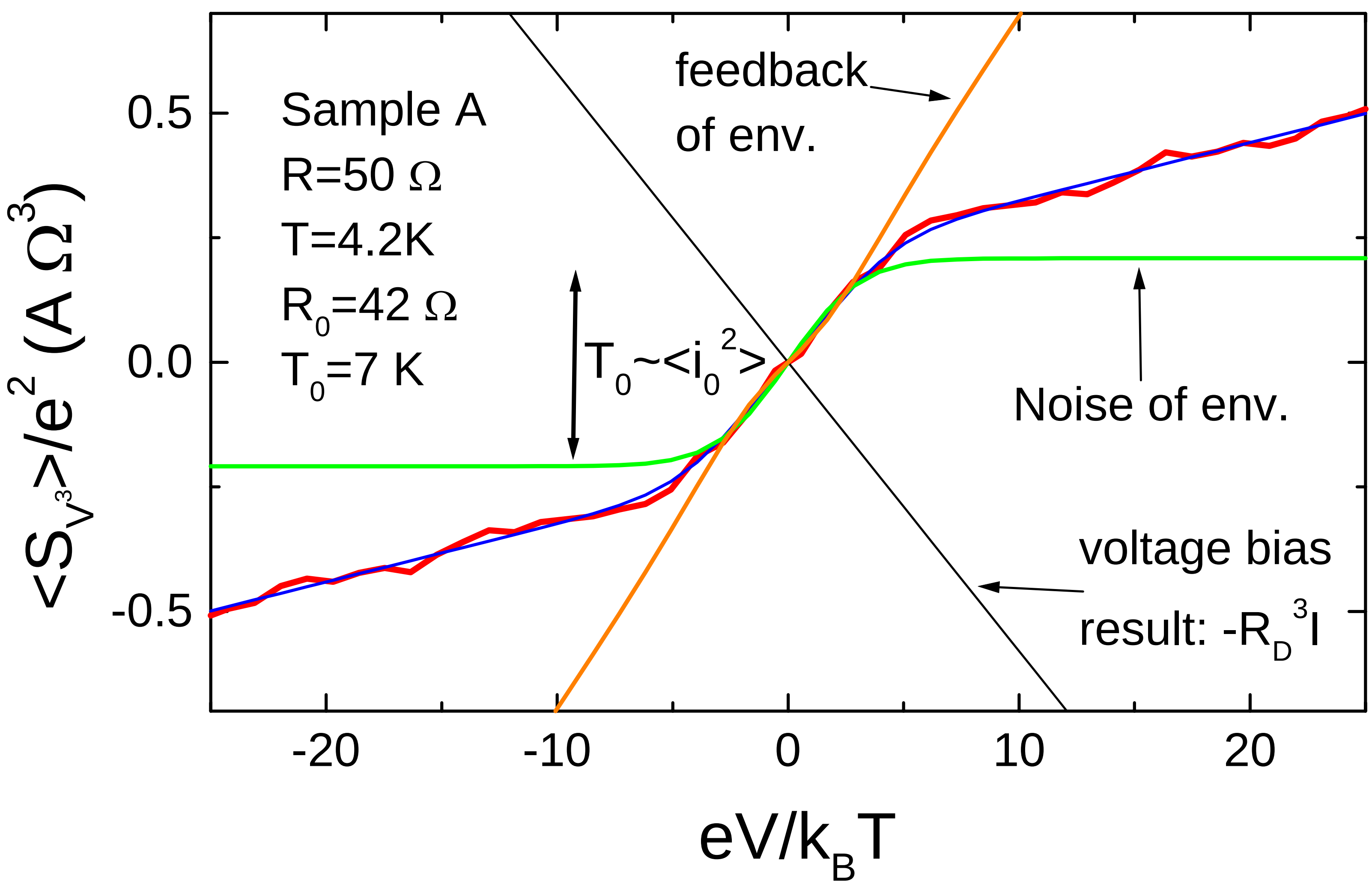
$S_3 = e^2 I\ [A^3/Hz^2]$

Lesovik, Levitov

Properties:

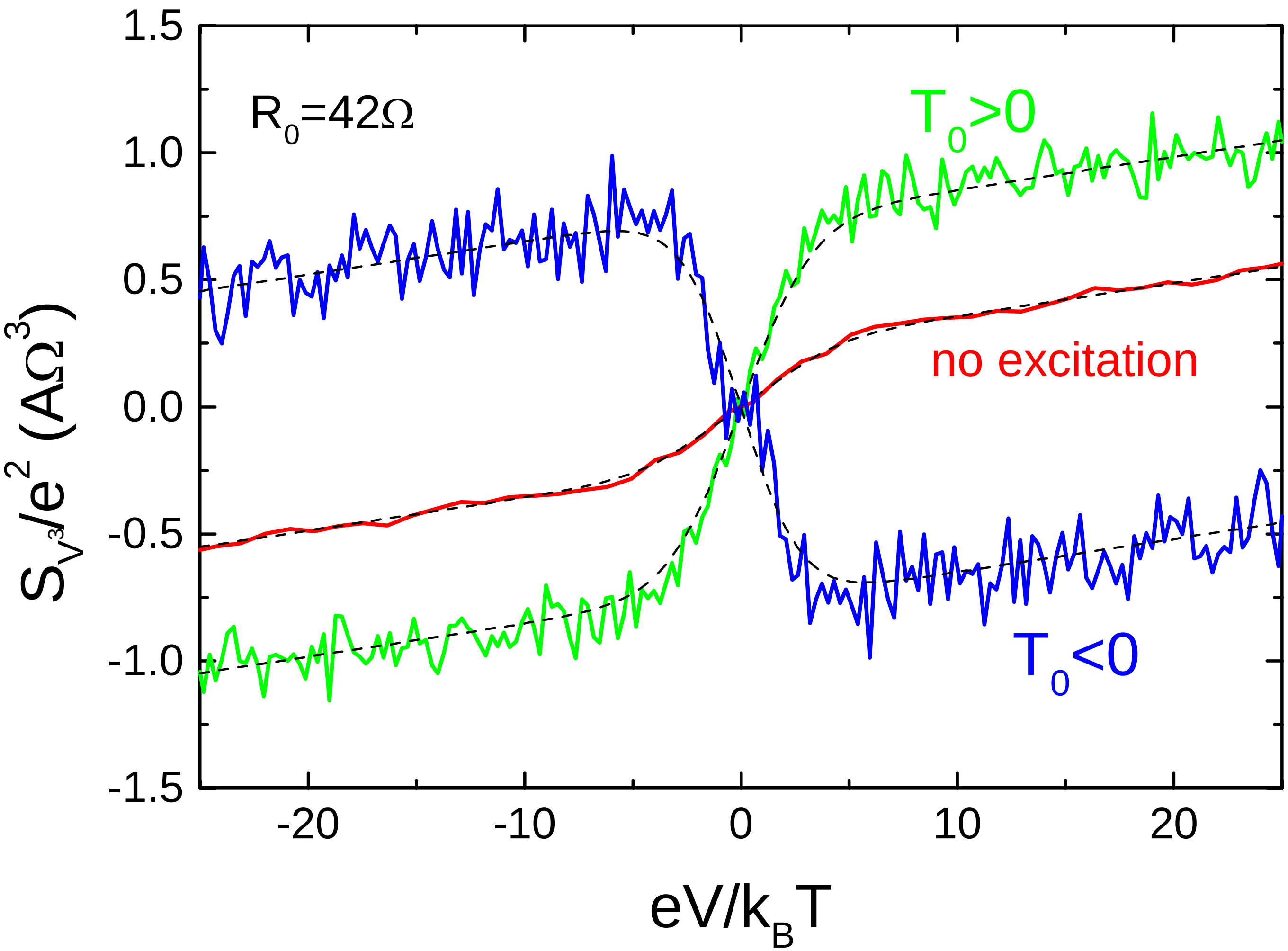
* an odd function of I (zero for I=0);
* independent of temperature !!
* magnitude and freq. dependence = diagnostic of qm in mesoscopic device

Exp. Result + theory: sample A



Noise of the environment – S_3 is difficult, but now is tamed

$$i_0(t) = A\cos\Omega t \quad T_0 \propto \left\langle i_0(t) i_0(t-2\Delta t) \right\rangle \propto A^2 \cos 2\Omega\Delta t$$



$$2\Omega_1\Delta t \equiv 0[2\pi]$$

$$2\Omega_2\Delta t \equiv \pi[2\pi]$$

Some open questions

Other systems:

• diffusive wire, NS interface, carbon nanotubes, etc…

• magnetic materials ?

• Phase transition ?

Quantum effects:

• Quantum noise: $hf>k_BT,eV$: intrinsic ? Environnement ?

• Effect of phase coherence ? $hf>\tau_\phi^{-1}$?

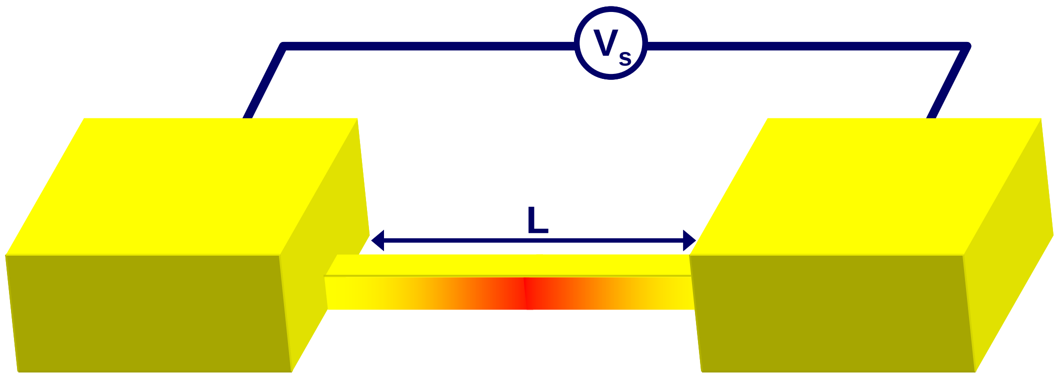
Finite frequency effects:

• diffusive wire: frequency vs. diffusion time, sensitive to e-e interactions (Pilgram, Nagaev, Buttiker)

Noise concepts

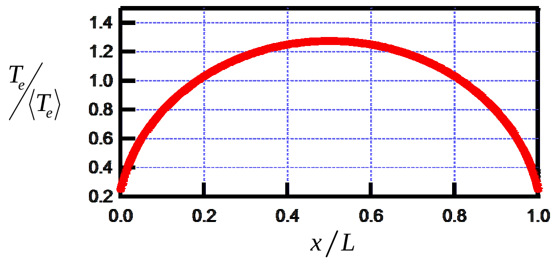
Equilibrium (Johnson) noise: V=0

$$i_n^2 = 4k_B TGB = S_2 B$$



Out-of-equilibrium noise

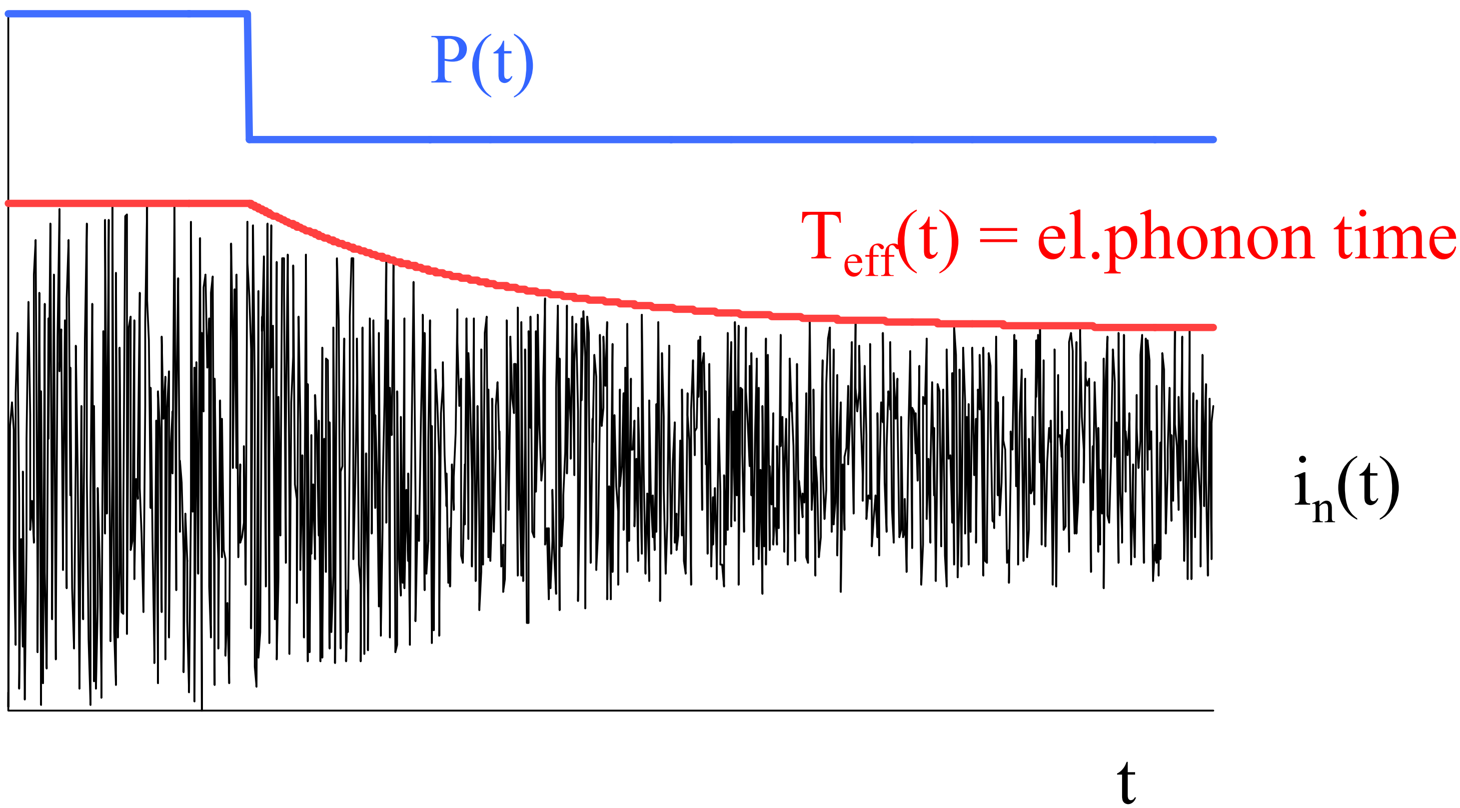
$$S_2(V) \to T_{eff} = S_2/(4k_B G)$$



e.g., heating by Joule power

S_2 is frequency independent up to 10^{12}-10^{14} Hz
It contains no information on the internal dynamics

Dynamics of $T_{eff}(t)$ under time-dependent drive

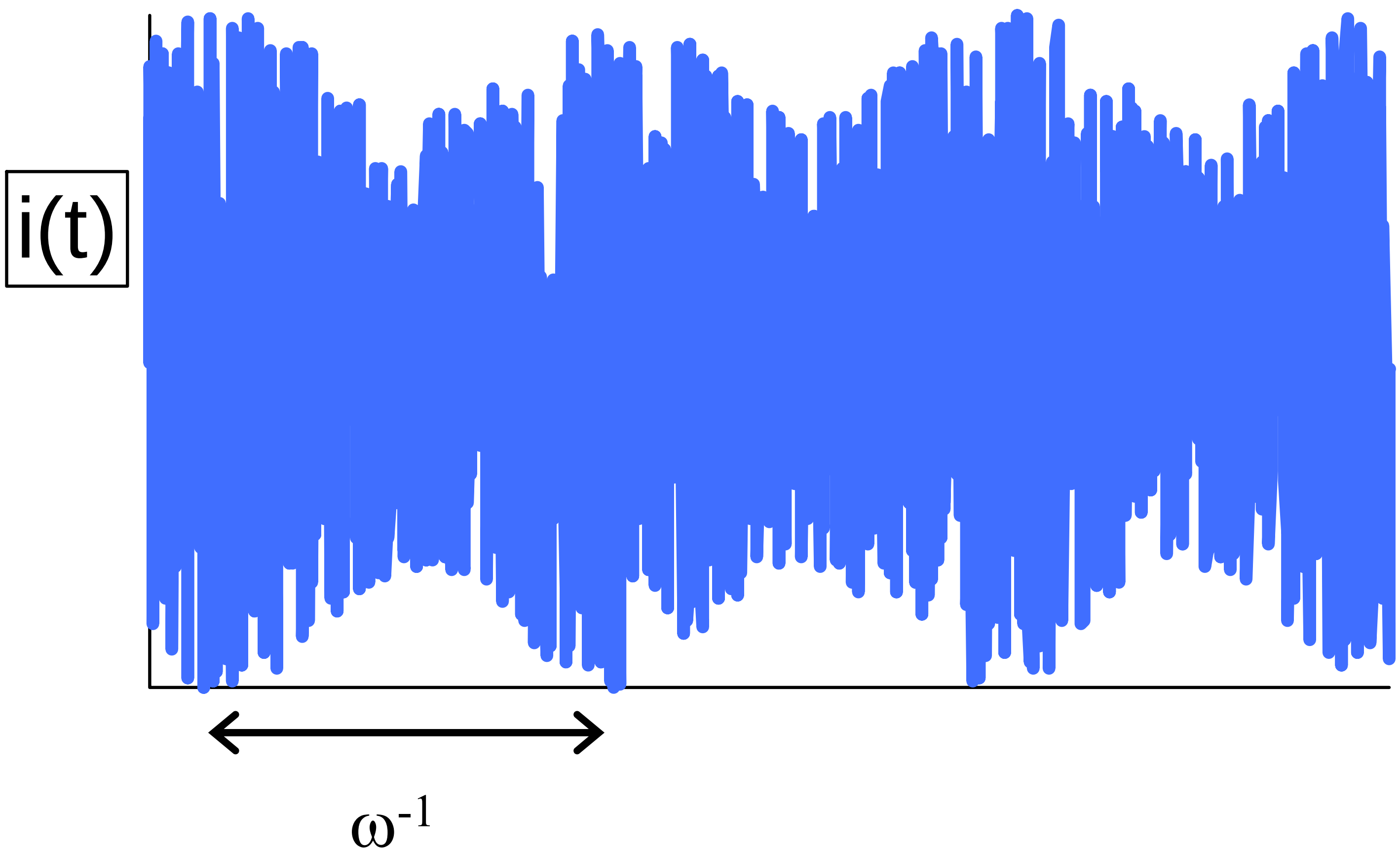


$T_{eff}(t)$ gives the thermalization time (electron-phonon, diffusion, etc.)

Modulation of noise: how fast ?

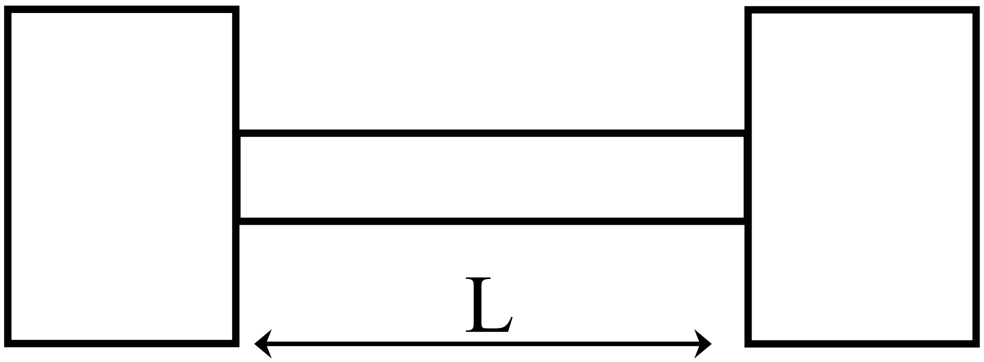
$$V(t) = V_{dc} + \delta V \cos \omega t$$

Relates to freq. dep. of S_3 for quantum cavities and wires



Which time is measured by $R_{Th}(\omega)$?

diffusive metallic wire: length L >> mean free path



$$L^2 = D\tau_D$$

See PRL ‘05

* long wire or SNS: phonon cooling

R(ω) gives the electron-phonon time

* intermediate wire: diffusion cooling

R(ω) gives the diffusion time

* short wire: elastic transport (independent electrons)

R(ω) gives the diffusion time

* ballistic wire (nanotube), quasi-crystals (sub-diffusive), …

Devices for Johnson noise thermometry

1. Long Au wire with Au leads.

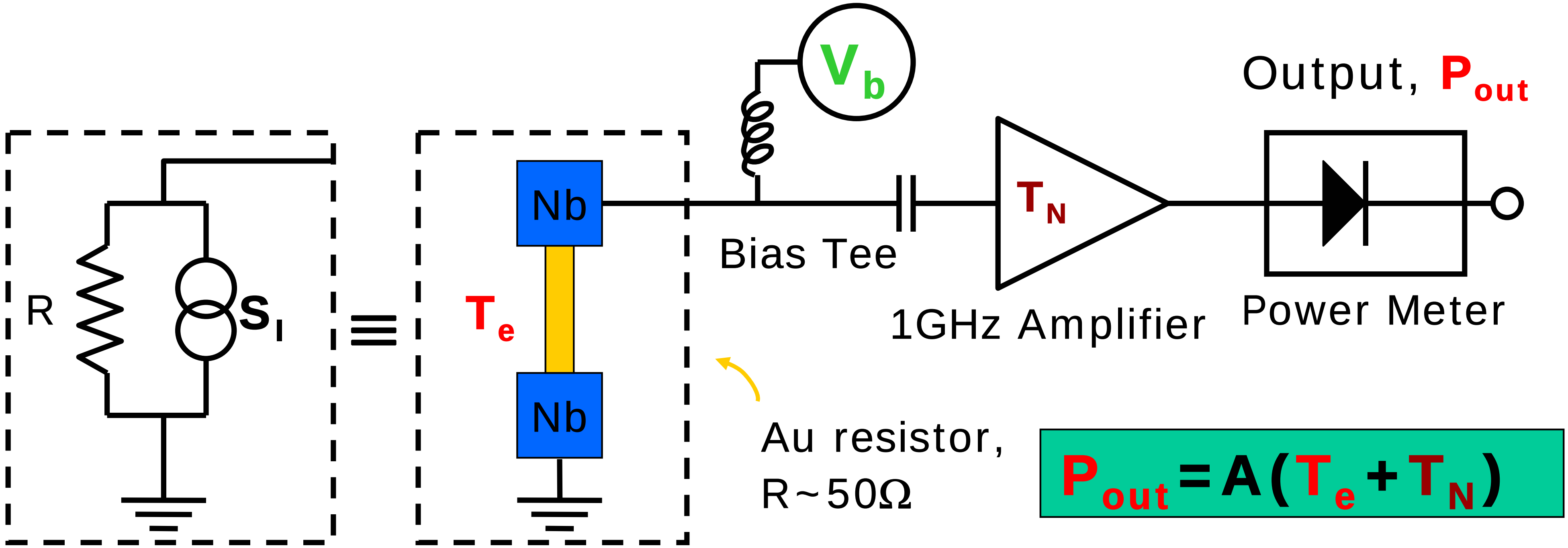
   $L \gg l_{e\text{-}ph}$

   1 mm x 30 μm x 20 nm

2. Short Au wire with SC Nb leads

   10 μm x 0.5 μm x 20 nm

Microwave Noise Thermometry



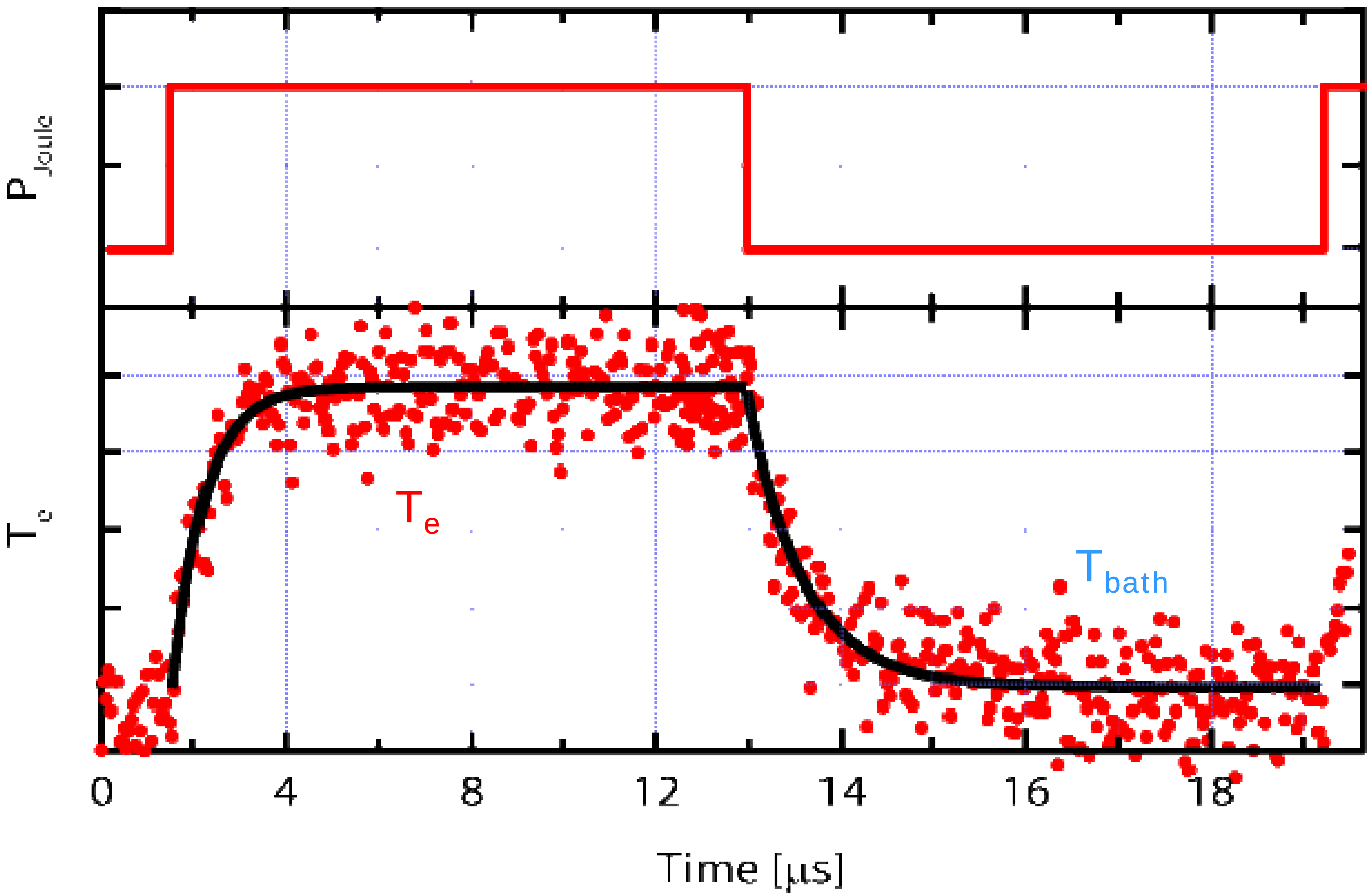
- High Sensitivity

$$\Delta T_e = T_N/(B\tau)^{1/2} = \text{mK} \qquad \text{for } \tau = 1s,\ B \sim 10^8\ Hz$$

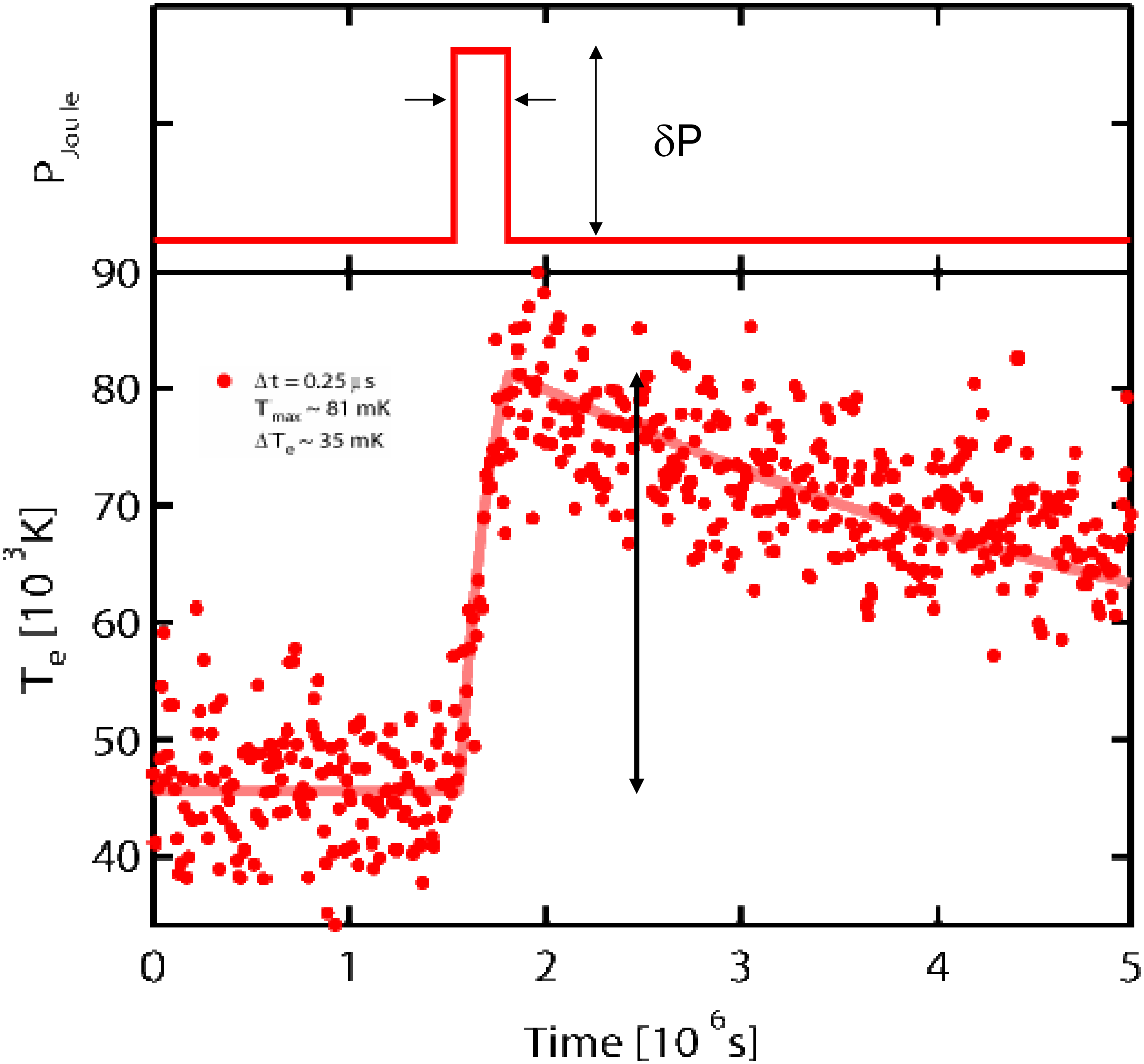
- Fast time response ~ 80ns, good for $\tau_{e\text{-}ph} \sim ns \rightarrow \mu s$

Cooling Dynamics

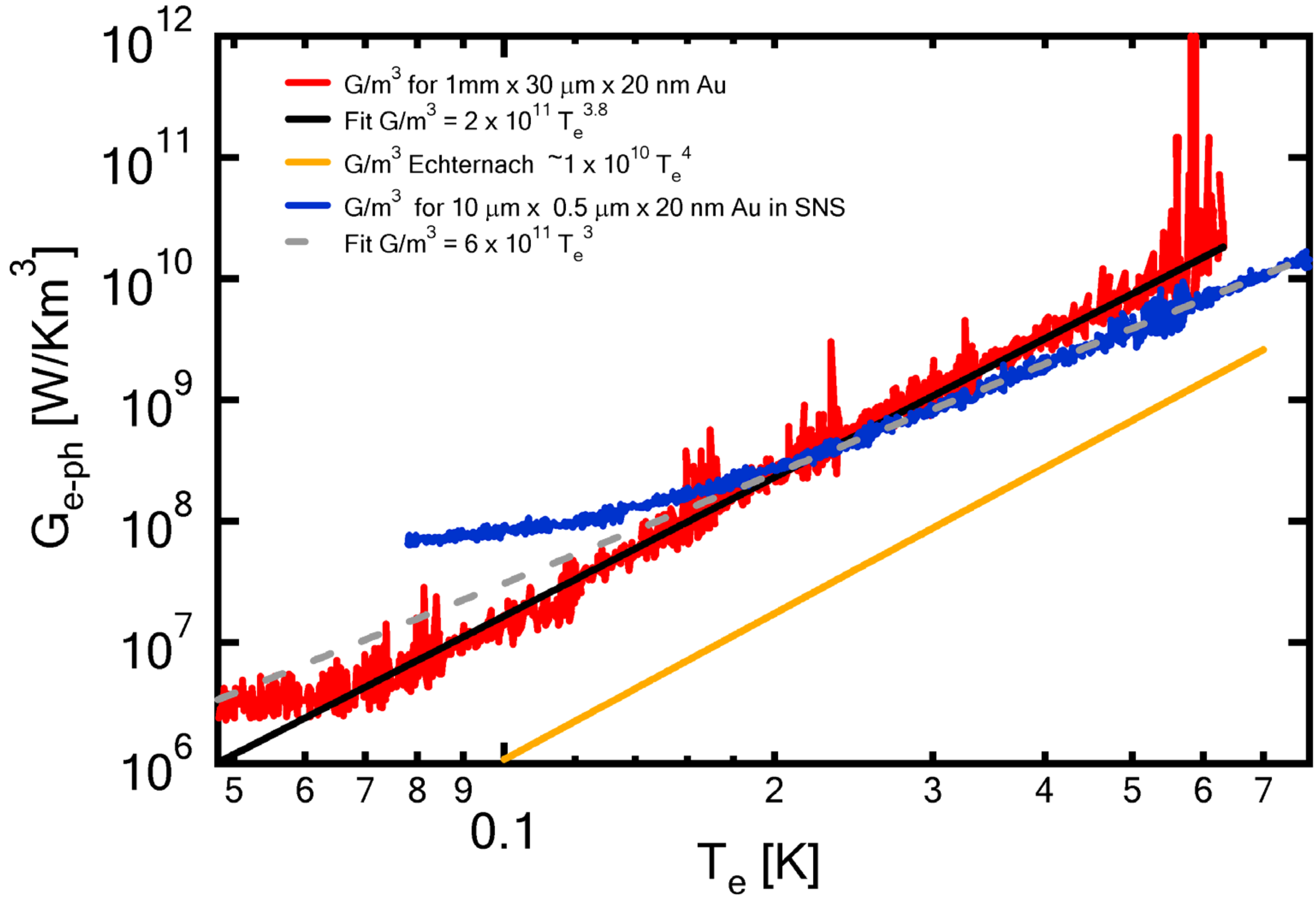
1. τ @ T_e 2. τ @ T_{bath}



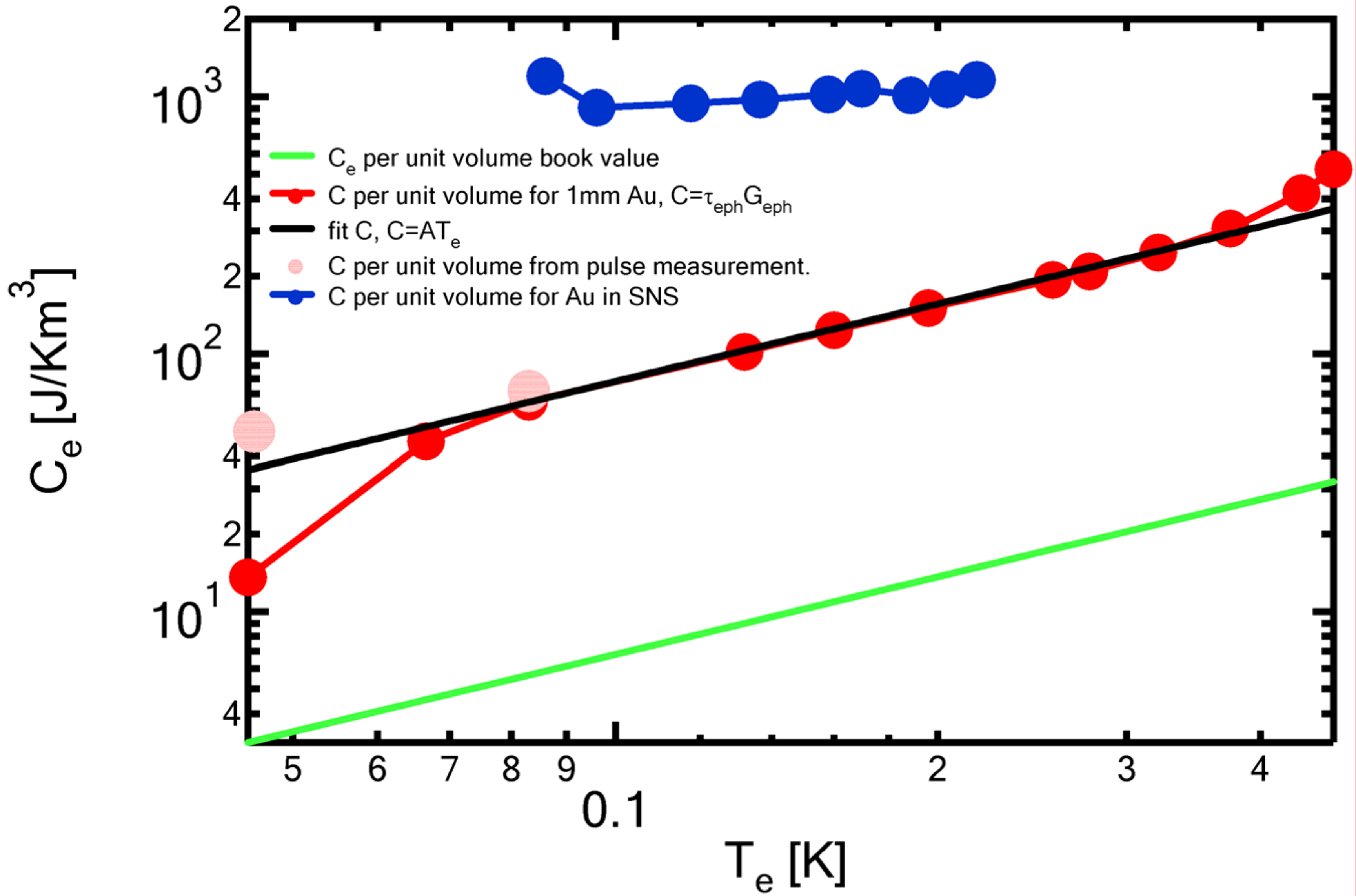
Calorimetry for C_e



G_{e-ph} from T_e vs. P_{Joule}



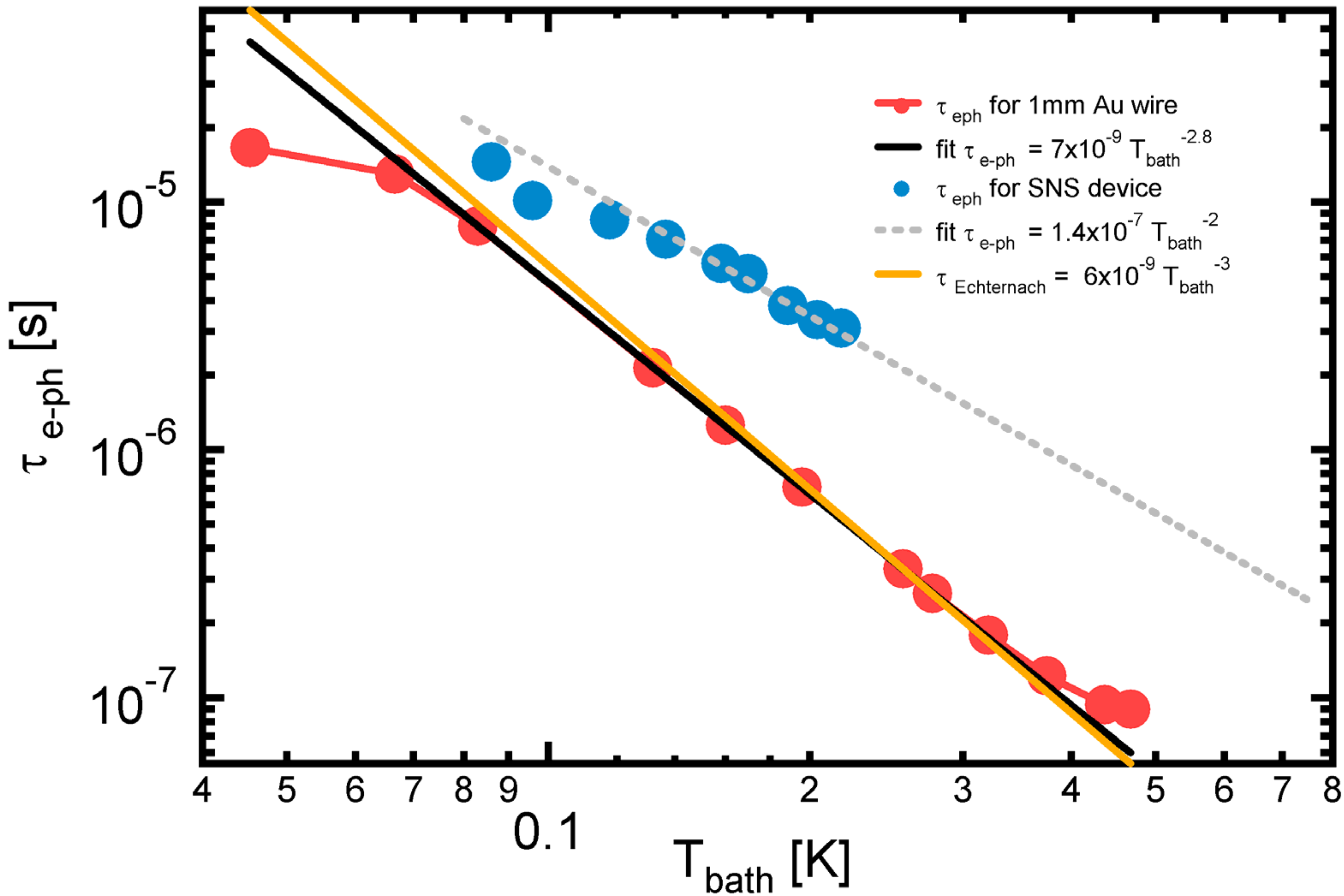
C_e



$C_e \sim 10\ C_{e\_book}$

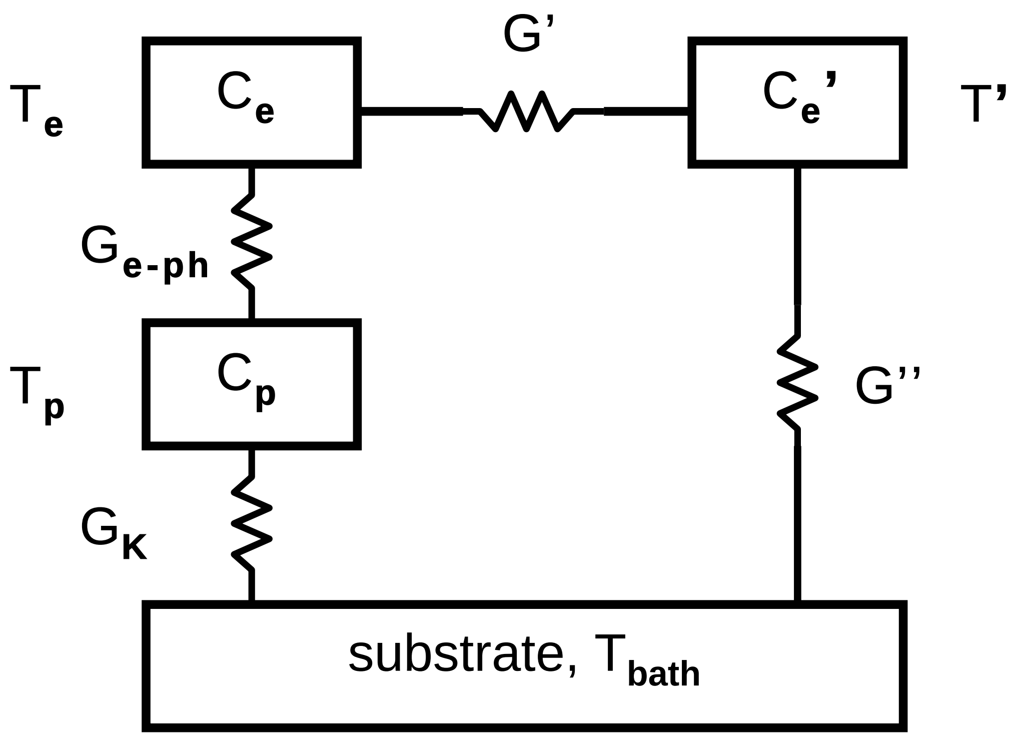
$C_e \sim 100\ C_{e\_book}$

$\tau_{e\text{-}ph}$



τ eph for 1mm Au wire
fit τ e-ph = 7x10^-9 T bath^-2.8
τ eph for SNS device
fit τ e-ph = 1.4x10^-7 T bath^-2
τ Echternach = 6x10^-9 T bath^-3
τ e-ph [s]
10^-5
10^-6
10^-7
4 5 6 7 8 9 0.1 2 3 4 5 6 7 8
T bath [K]

Possible Thermal Structure



$G' >> G_{e\text{-}ph}$ and

$G' >> G''$ → $T' = T_e$

$C_e = \gamma_e T_e$, $C_e' = A \gamma_e T_e$

$C_{eff} = C_e + C_e'$

$G_{eff} = G_{e\text{-}ph} + G''$

$C_{eff} / G_{eff} = \tau_{eff} \sim \tau_{e\text{-}ph}$

What we learn

- **Electron-phonon (or inelastic) interaction time in dirty metallic wires – puzzling so far.**

- **Electron-electron interaction time in short wires – PRL '05 (there is no well-defined, single temperature)**

- **Physics of why i^3 is frequency dependent -- diffusion time; related to driven S_2**