

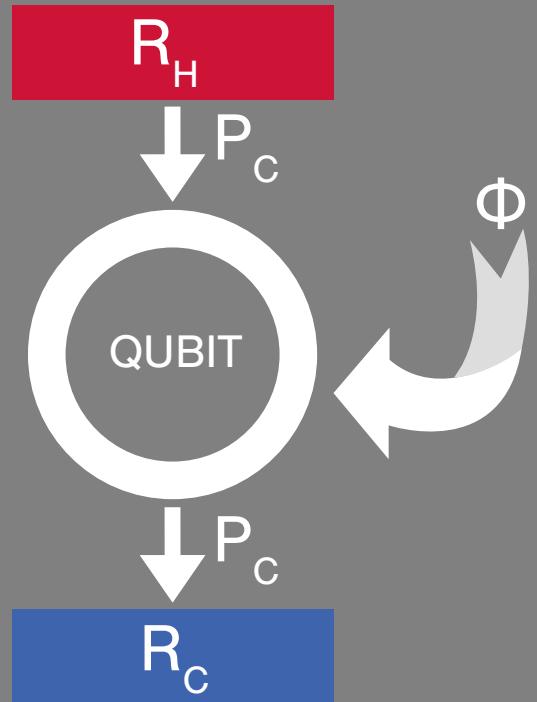


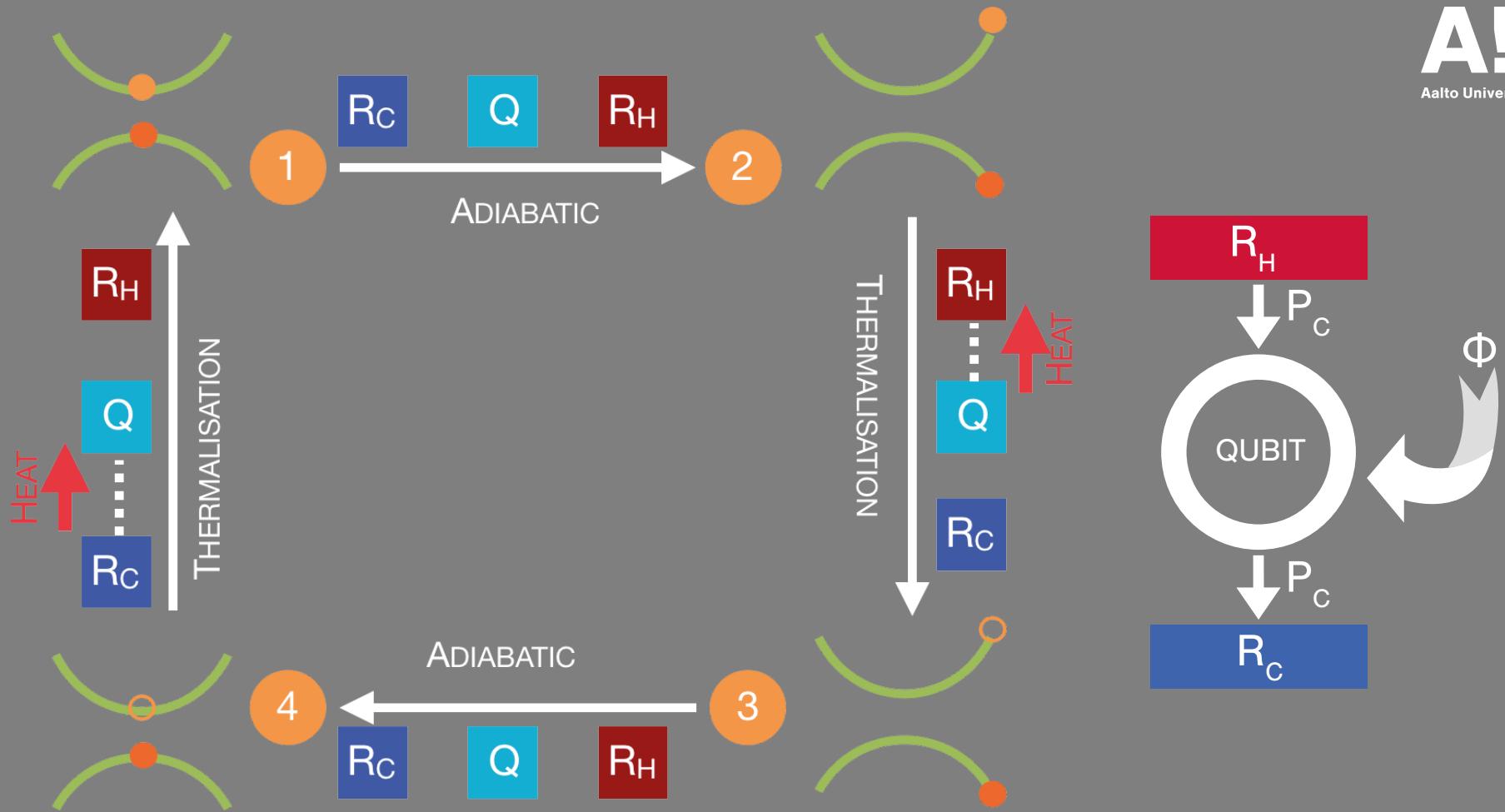
A!
Aalto University

Quantum Thermodynamics with Superconducting Circuits

APS March Meeting, Boston 2019

Towards a Quantum Heat Engine



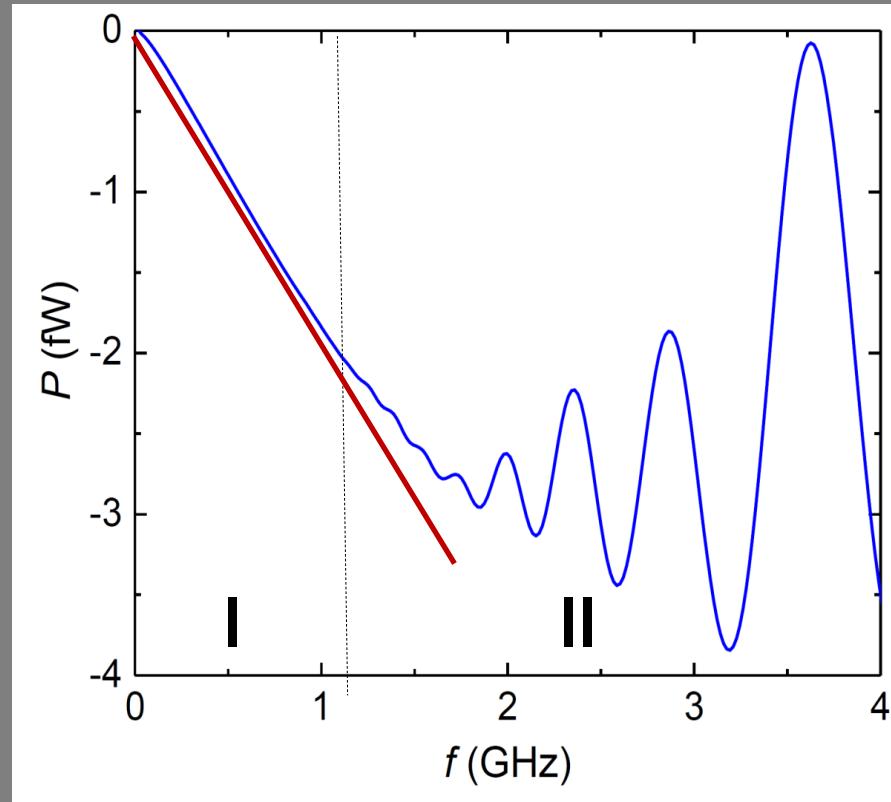


A. Niskanen, Y. Nakamura, J. Pekola, PRB 76, 174523 (2007)
 B. Karimi and J. Pekola, PRB 94, 184503 (2016)

Quantum heat engine (quantum Otto refrigerator)

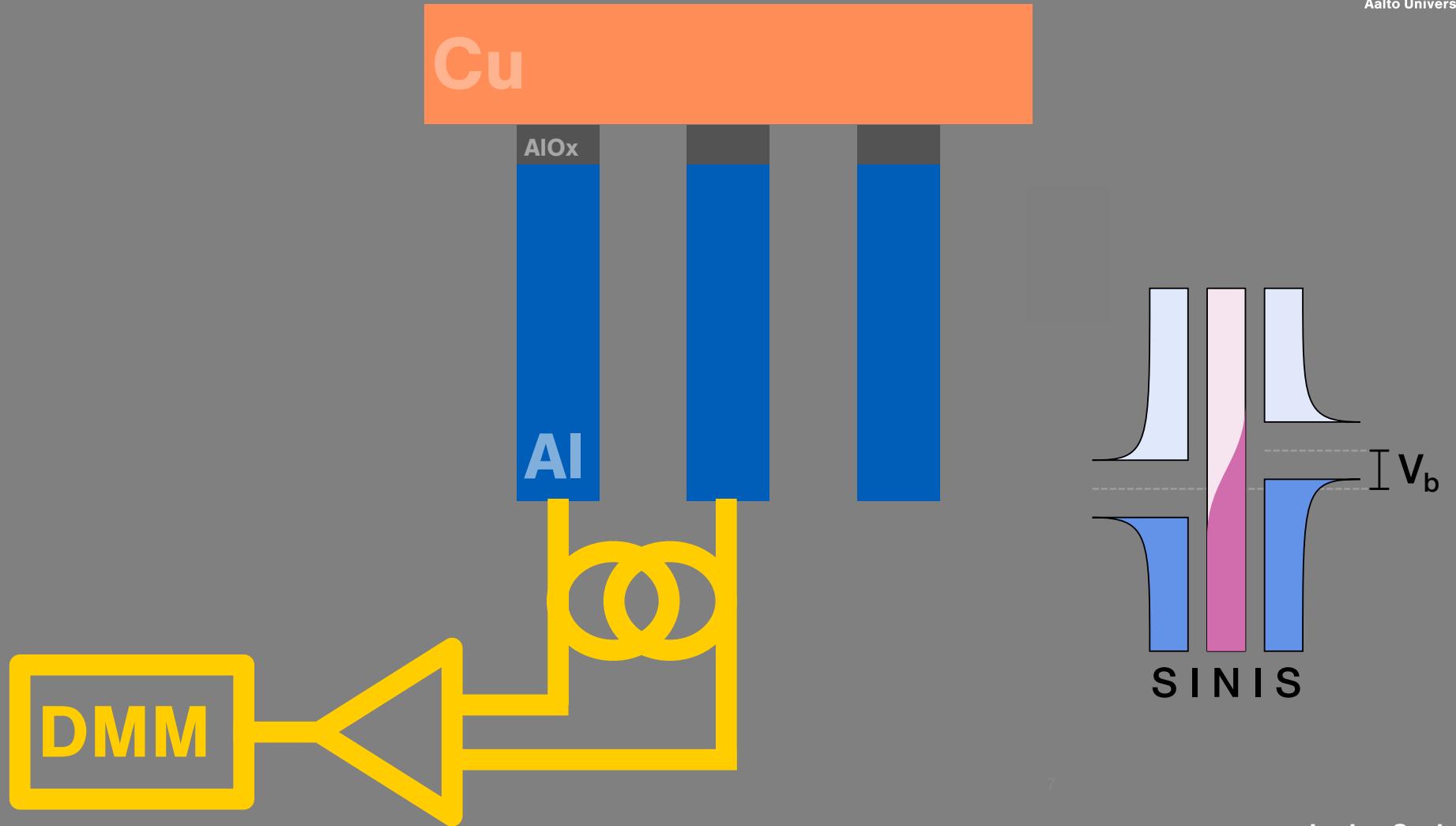
Different operation regimes:

- I. Ideal Otto cycle
- II. Coherent oscillations at high frequencies

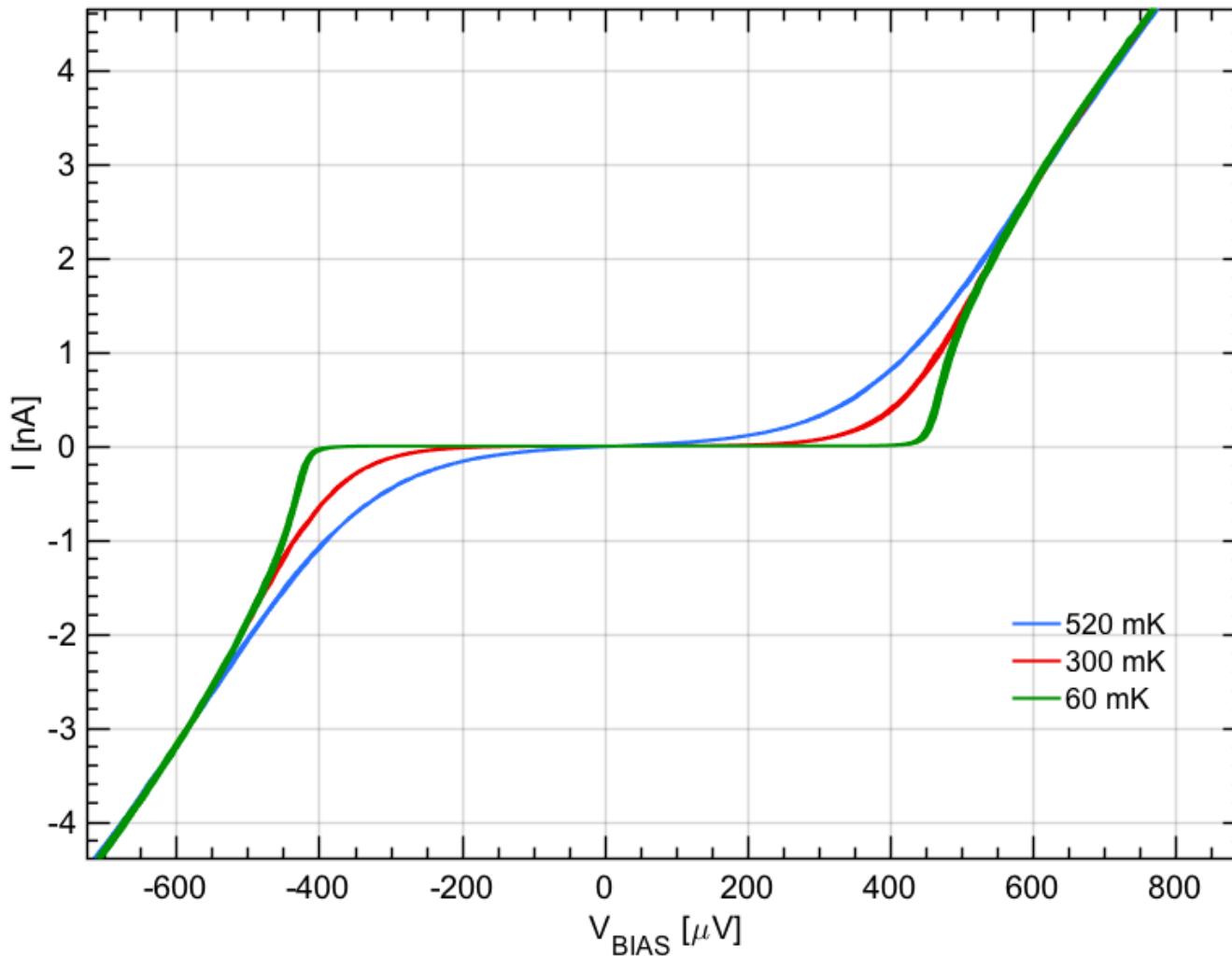


Let's build our
circuit...

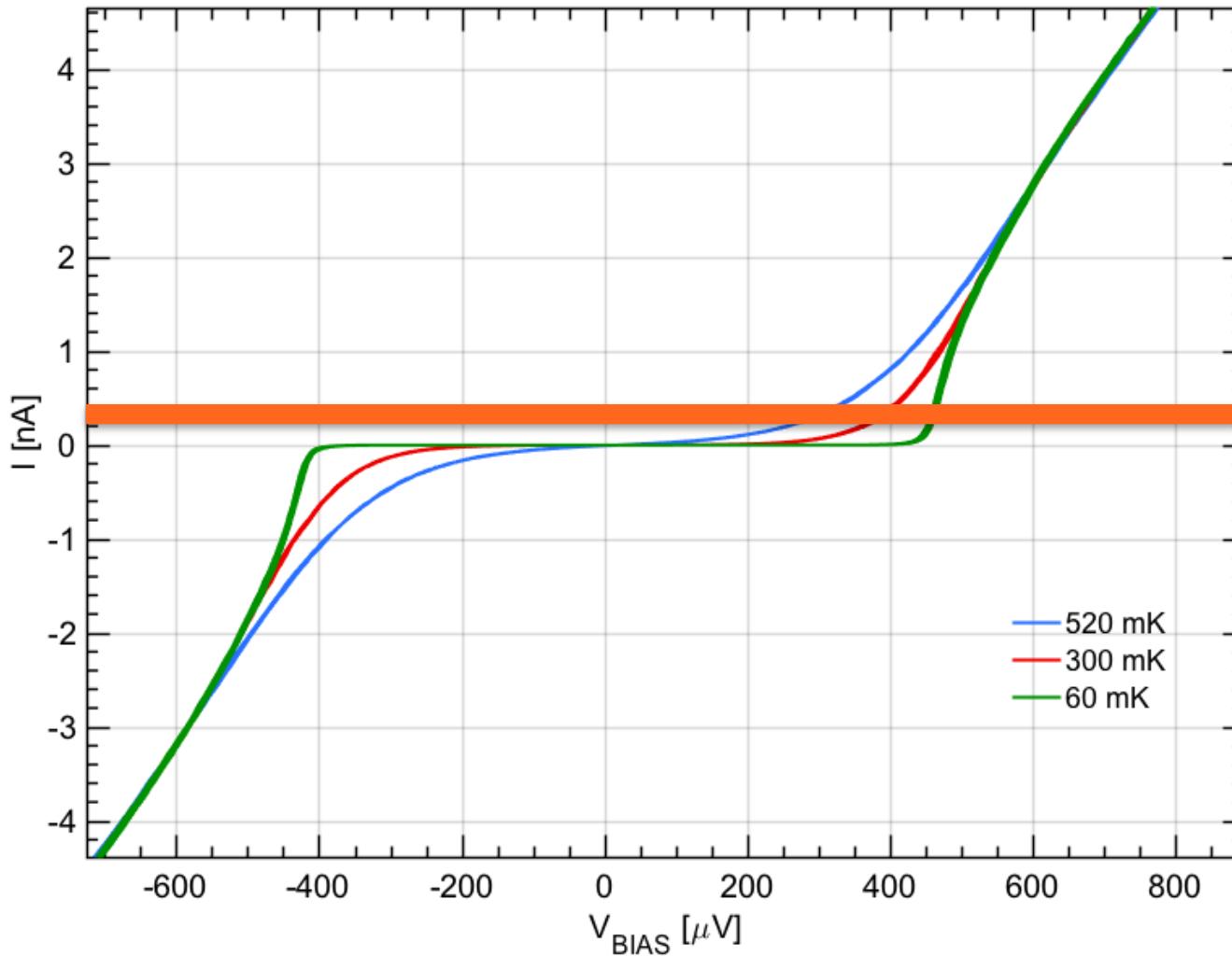
Cu

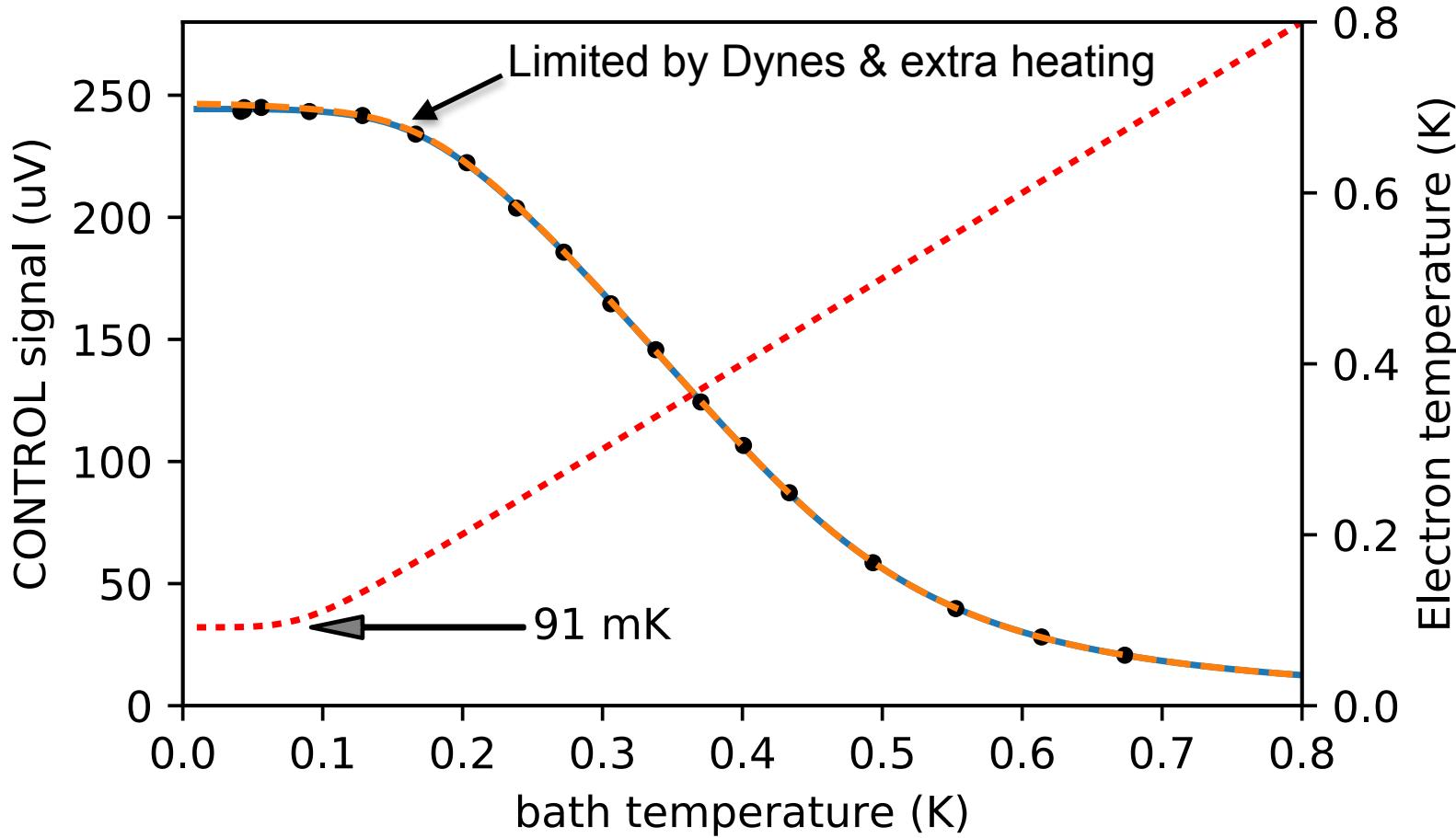


Temperature Sweep, Junctions A and B



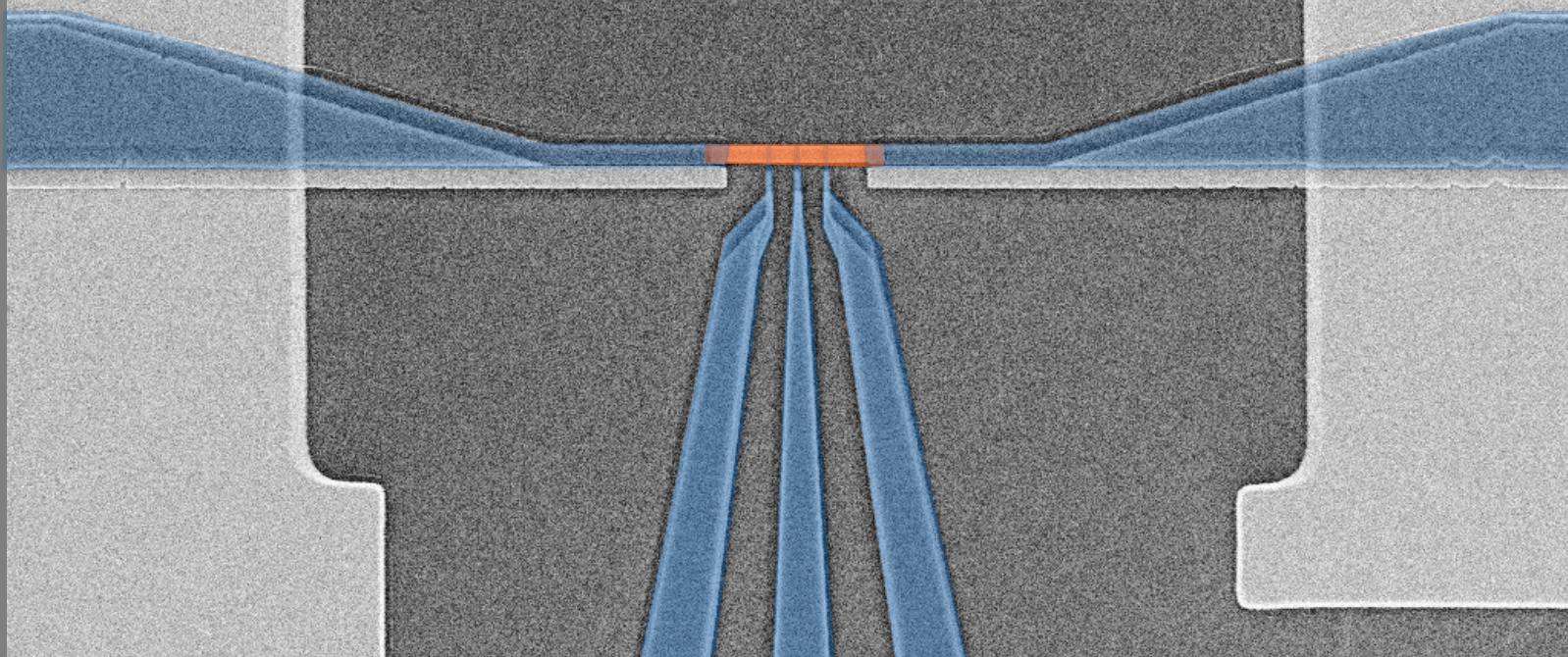
Temperature Sweep, Junctions A and B

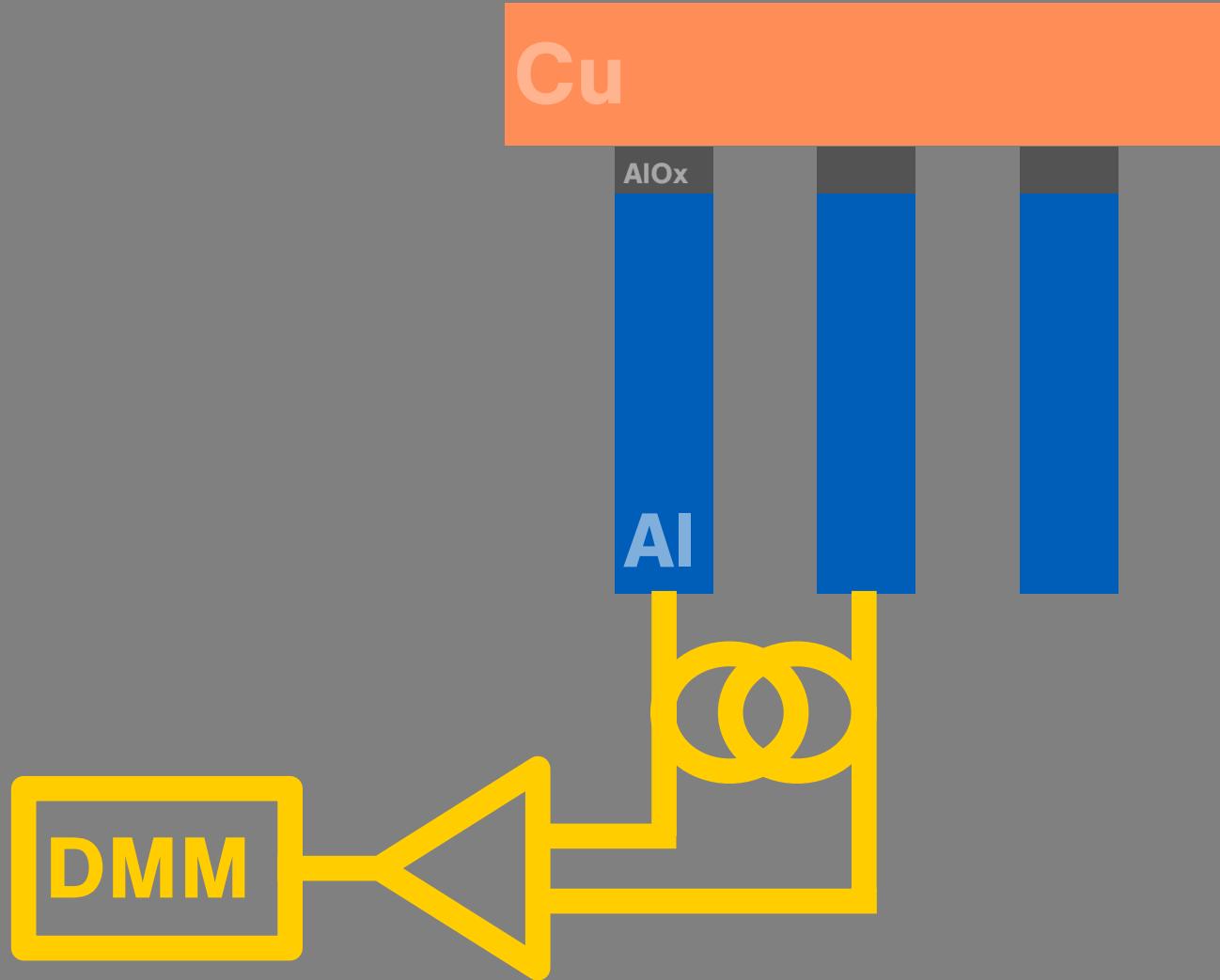


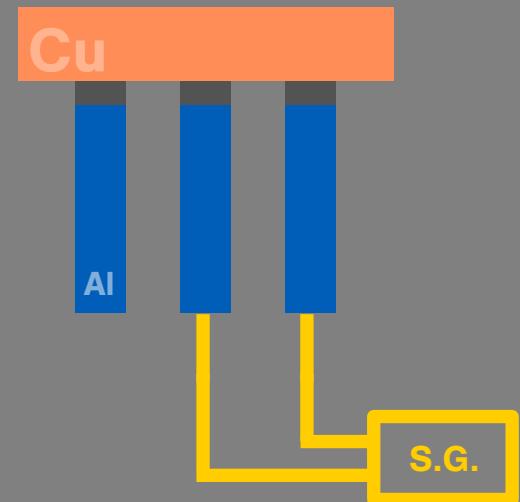
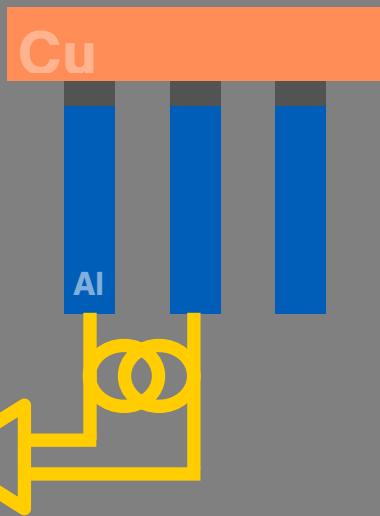


Ground

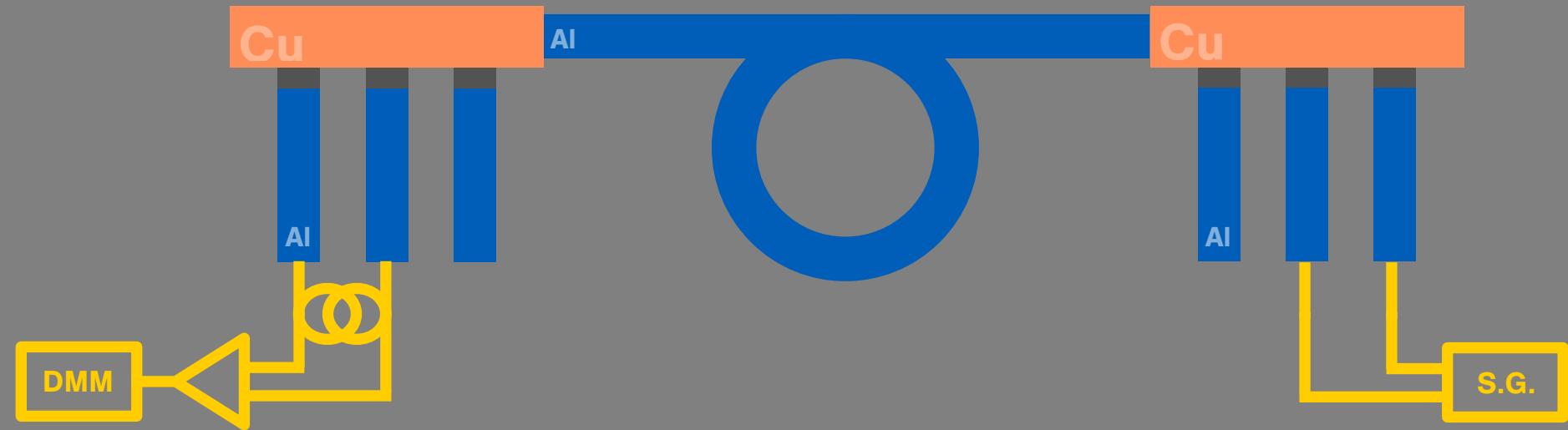
CPW







Schmidt et al., PRL 93, 045901 (2004)
Timofeev et al., PRL 102, 200801 (2009)

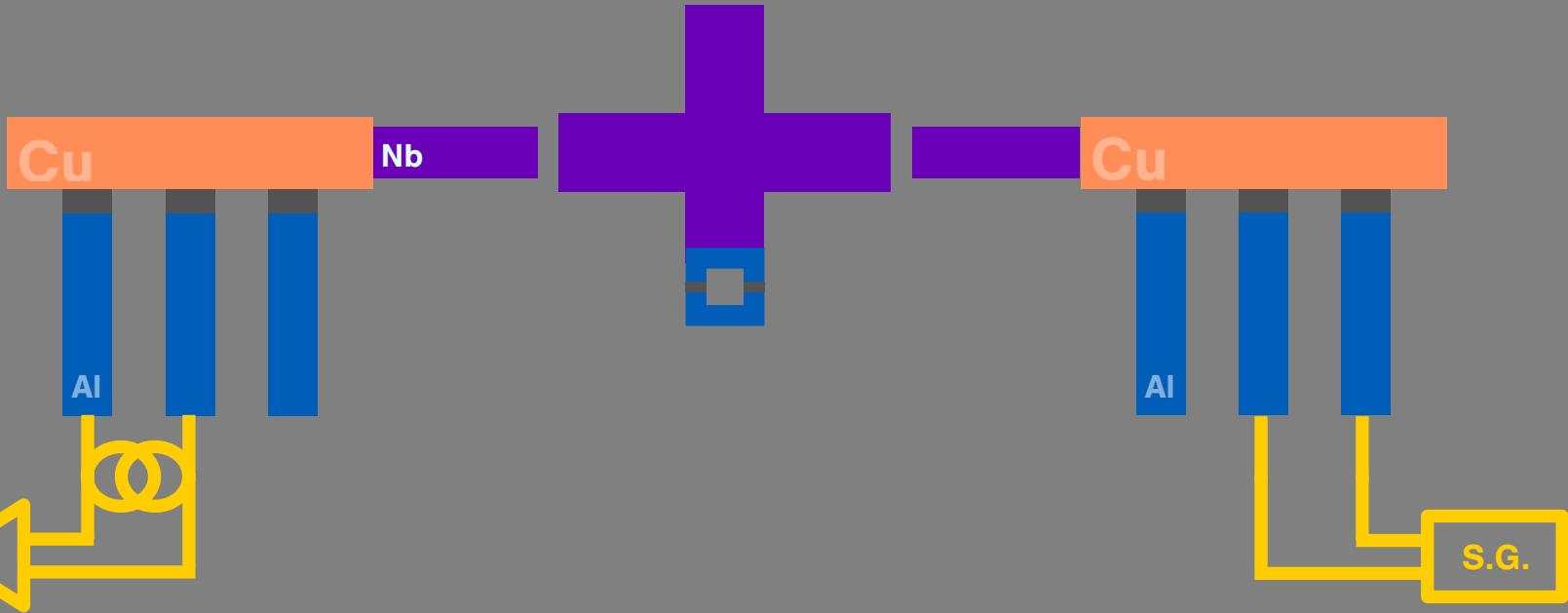


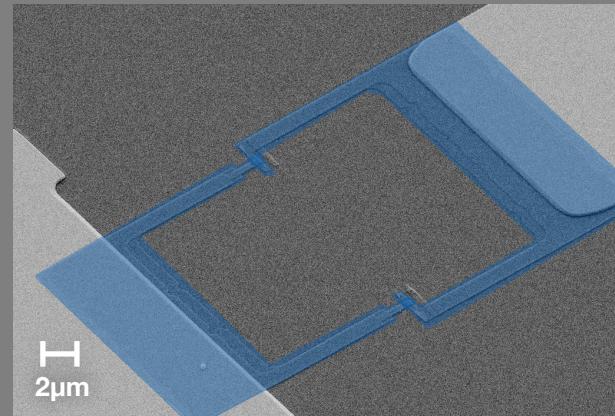
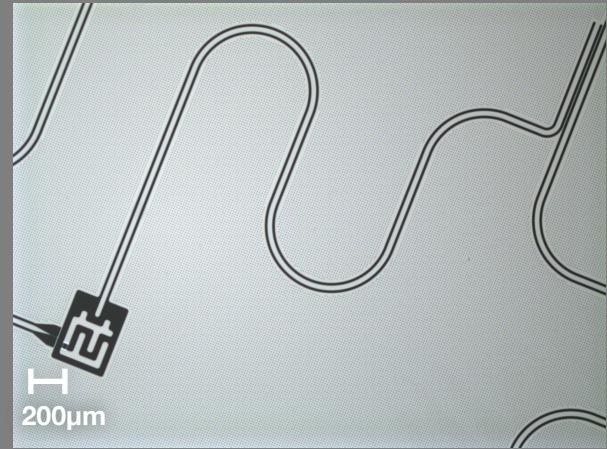
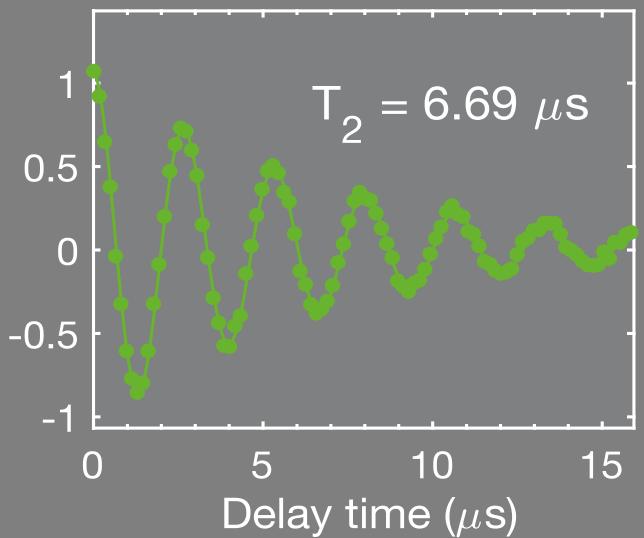
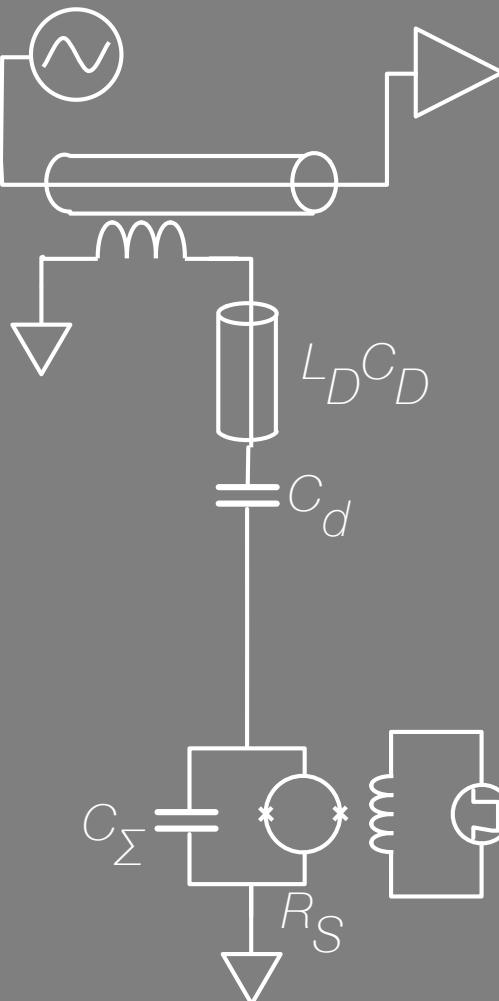
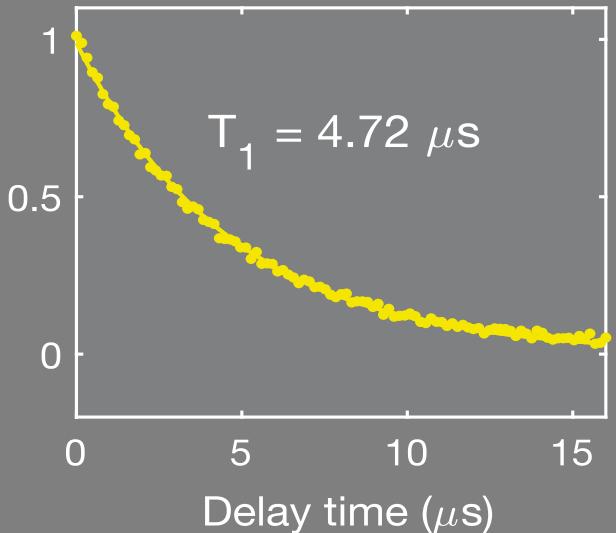
Photonic Heat Transport:

M. Meschke, W. Guichard and J. Pekola, Nature 444, 187 (2006)

'Quantum' of Heat Transport

M. Partanen et al., Nature Physics 12, 460 (2016)

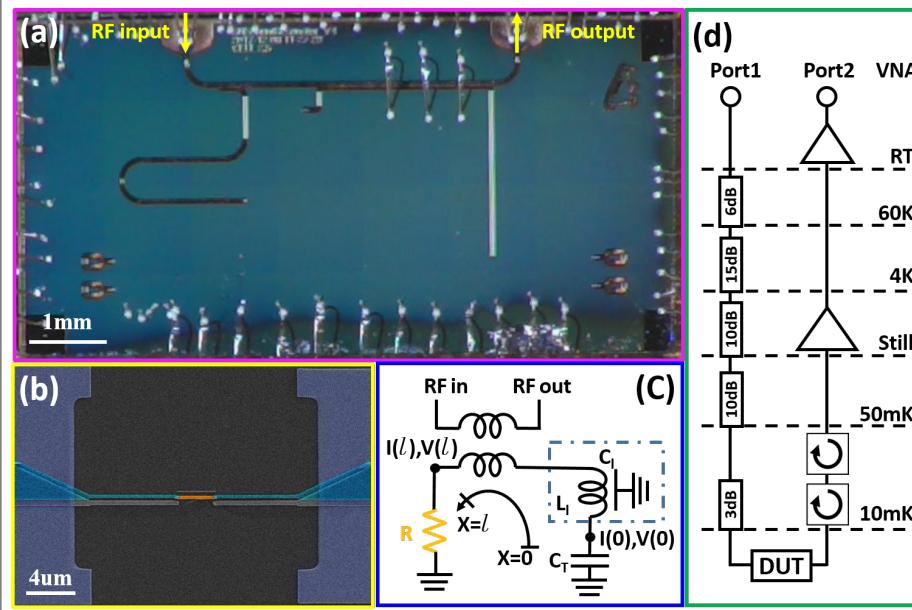




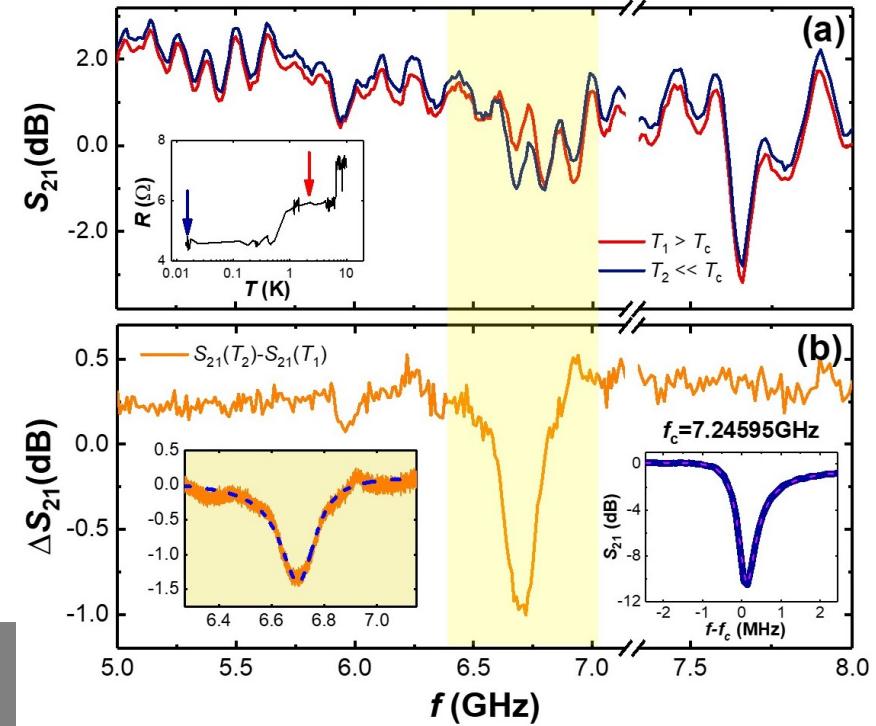
R. George, JS, et al, JLTP (2017)

Jorden Senior

What happens to Q of the resistively shunted resonators?



$$Q \approx 4 - 20$$



Half-way summary:

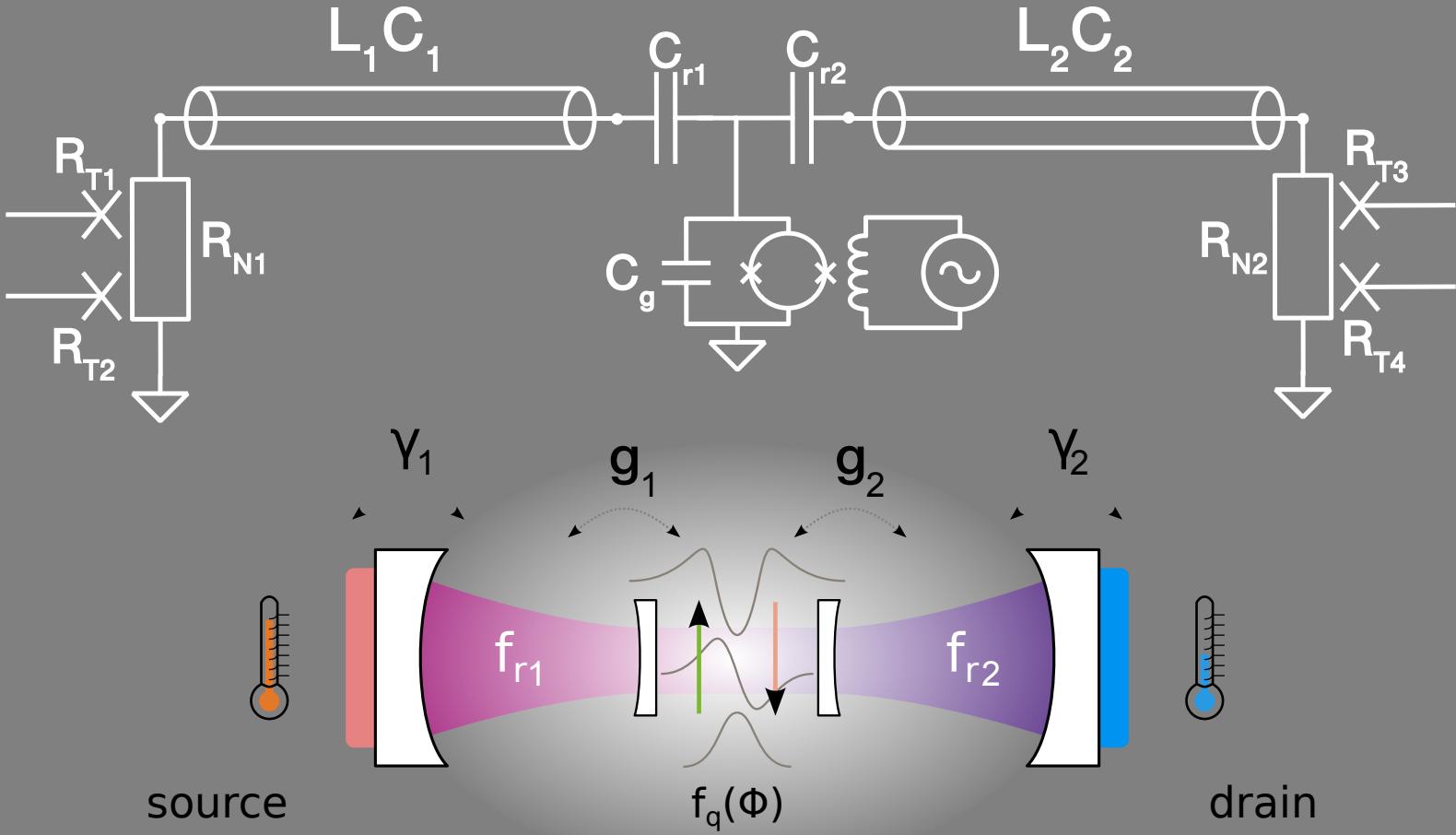
The goal is to develop a platform for looking at thermodynamics in an open quantum system (Otto engine)

We have our components:

- Ultra-sensitive thermal control and detection
- Artificial atom (superconducting transmon)
- Engineered microwave environment

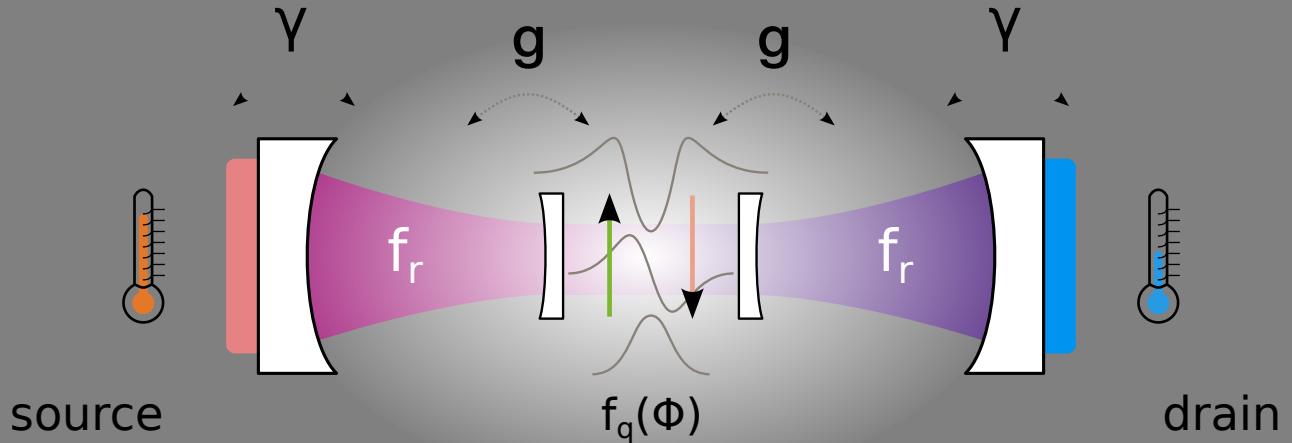
In Part II, let's put them all together to make a

Quantum Heat Valve

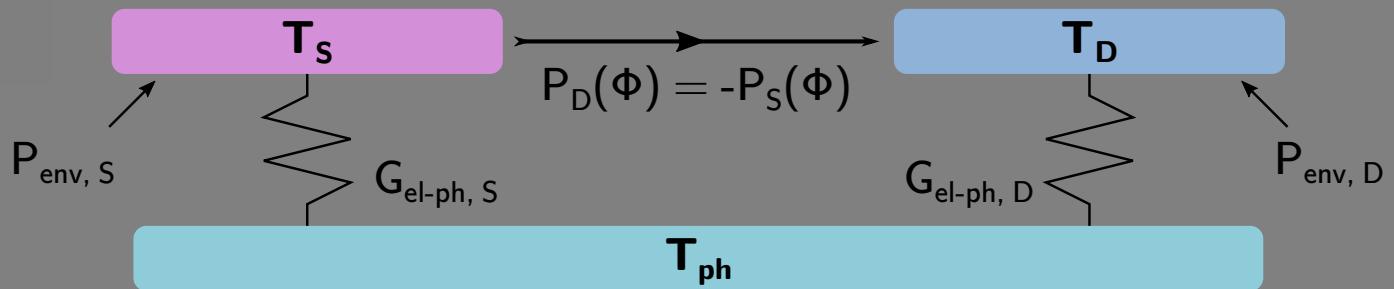


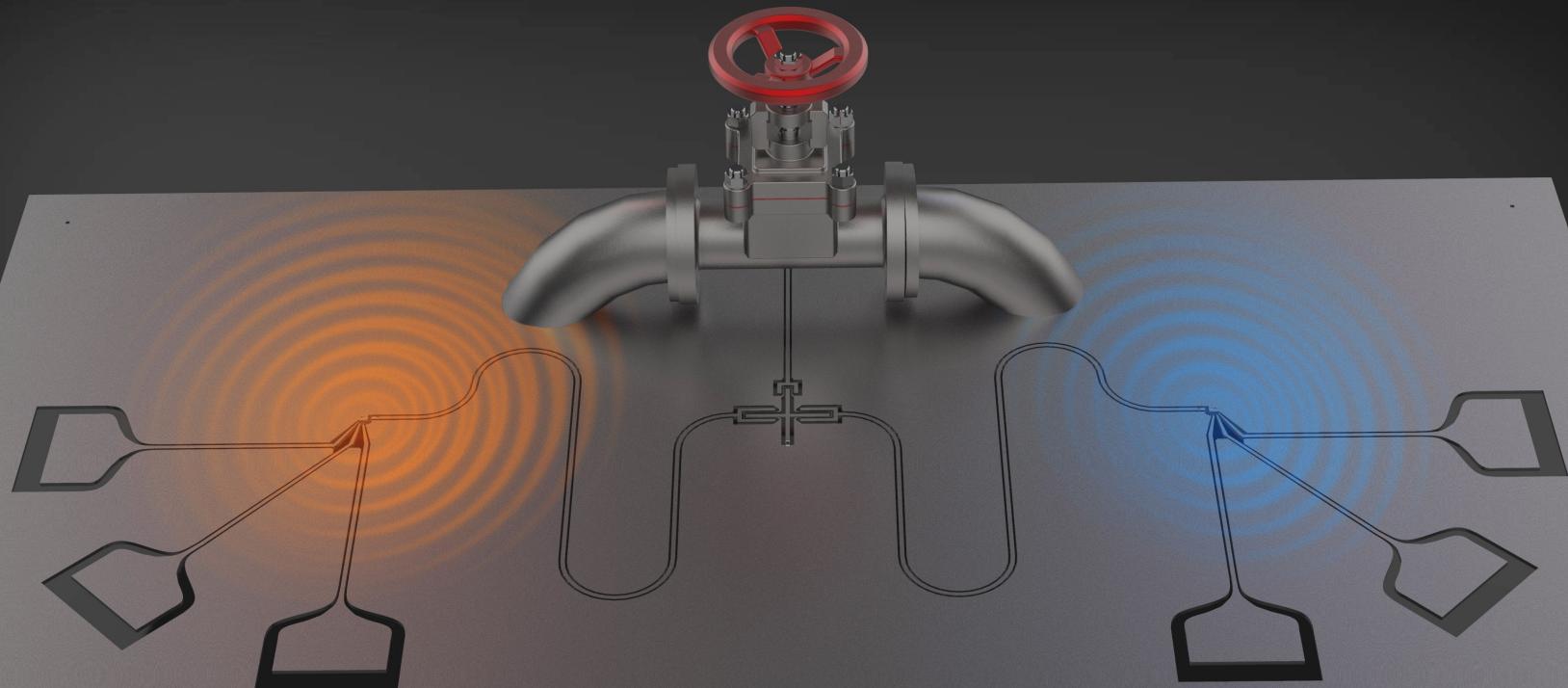
Large parameter space!

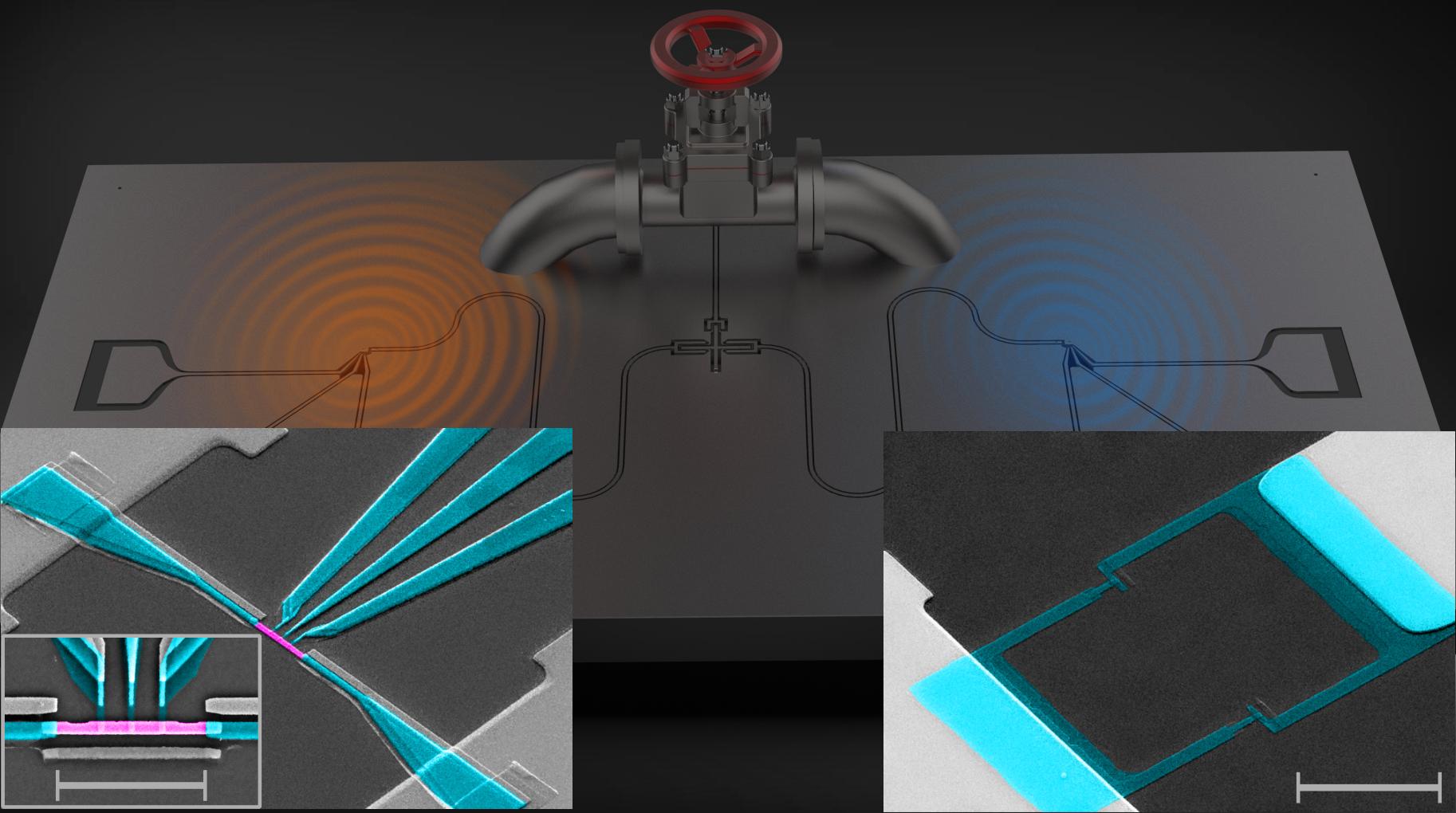
19

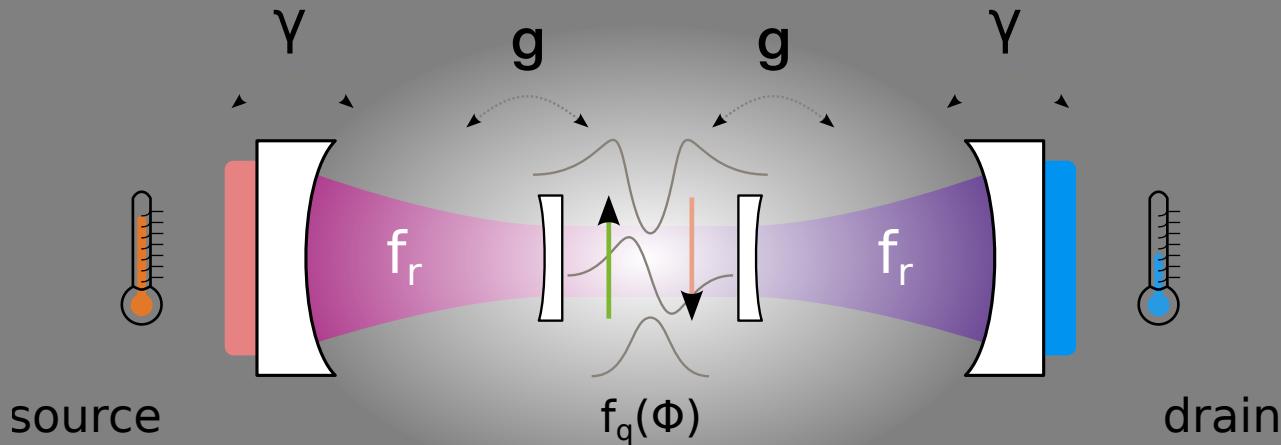


$$f_{r1} = f_{r2}$$









$$g/\gamma = 0.05$$

$$Q = 3$$

LOCAL

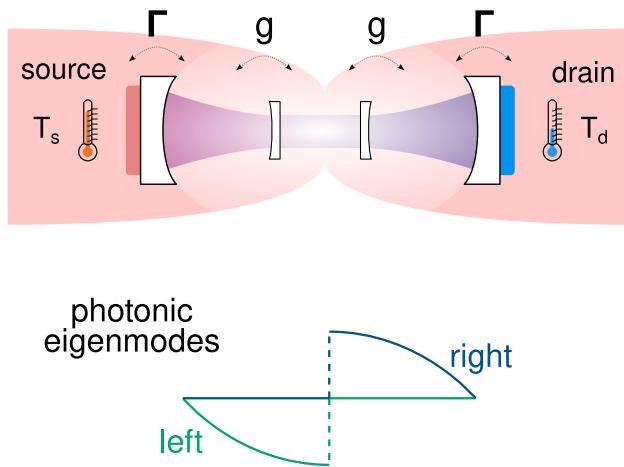
$$g/\gamma = 0.4$$

$$Q = 20$$

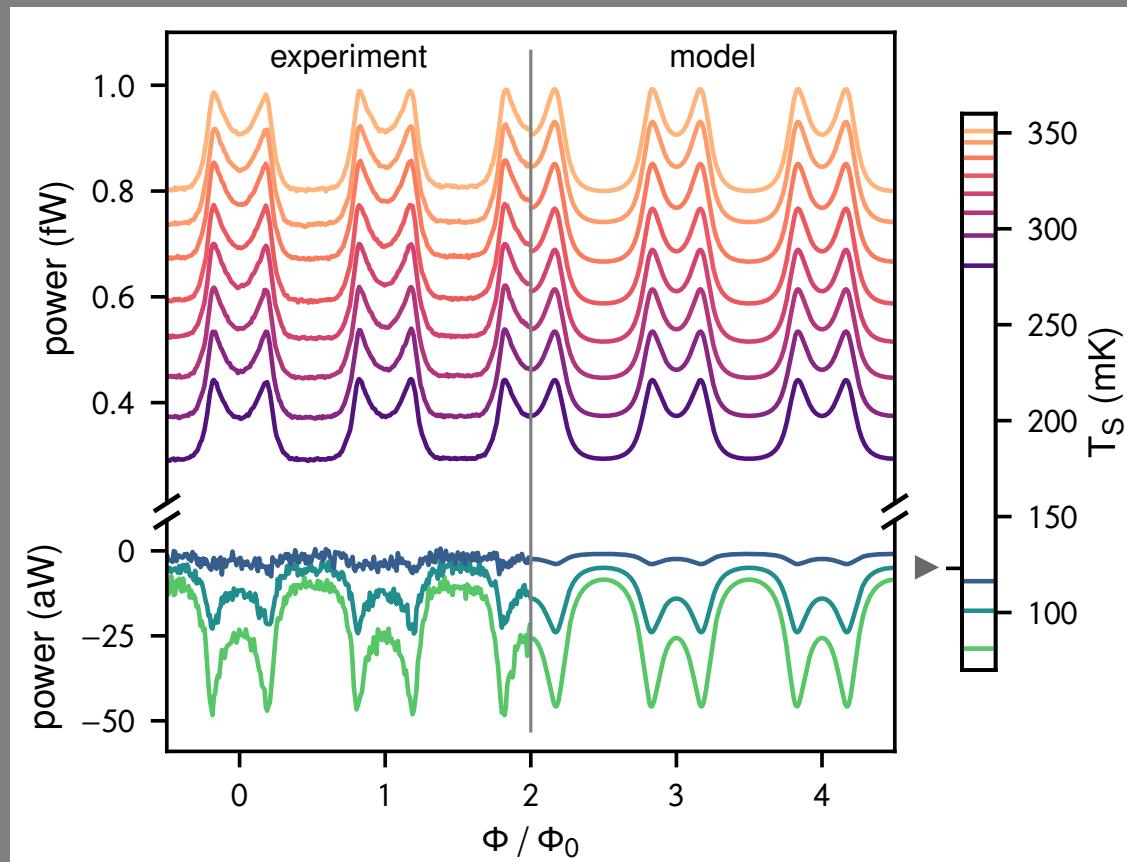
GLOBAL

$g/\gamma = 0.05$

$Q = 3$
LOCAL



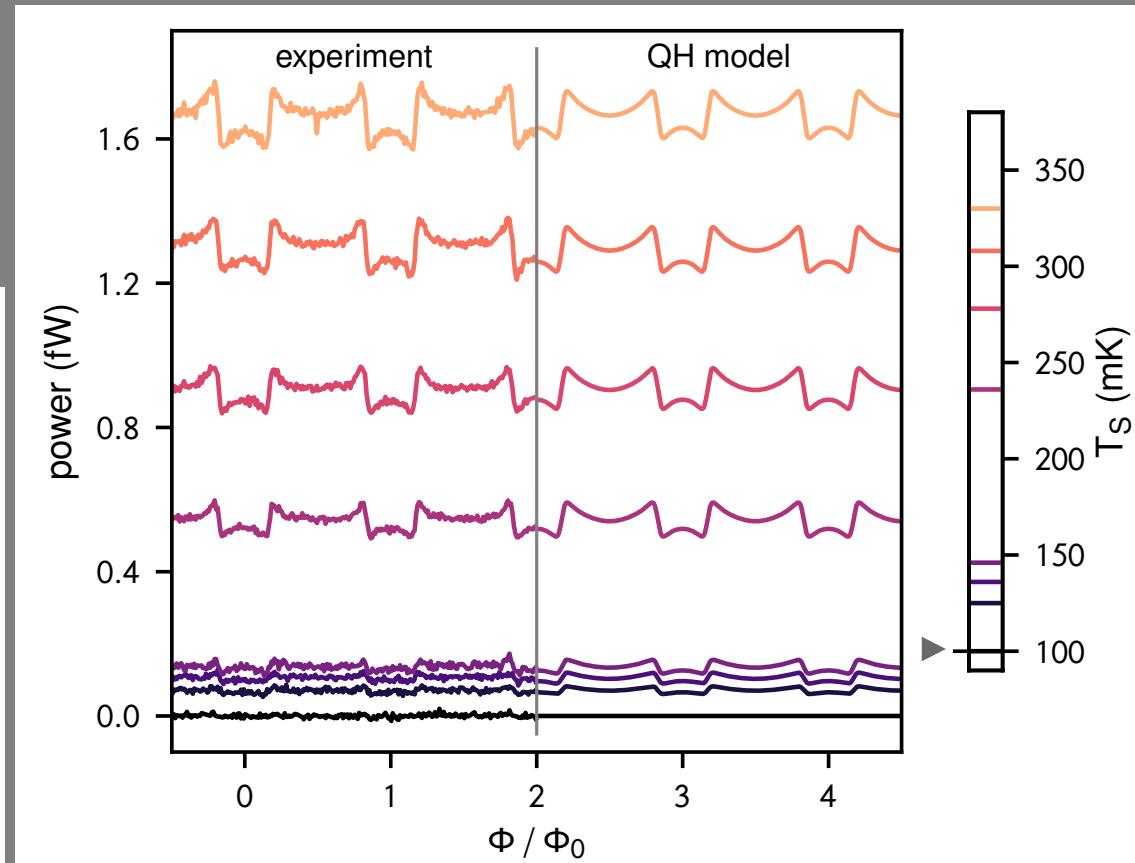
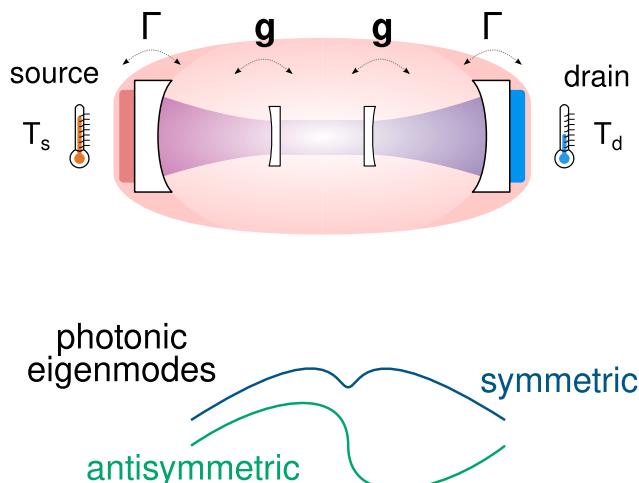
NEP ~ 5 aW
'wireless' cooling (4mm) of 50aW



$g/\gamma = 0.4$

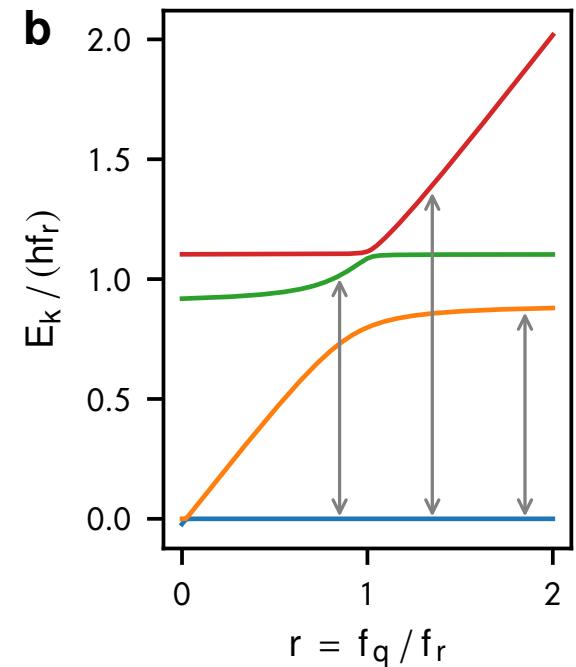
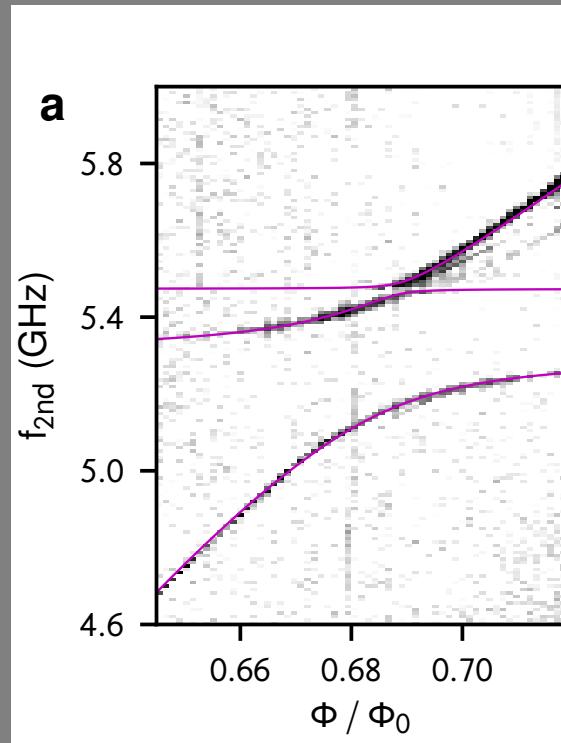
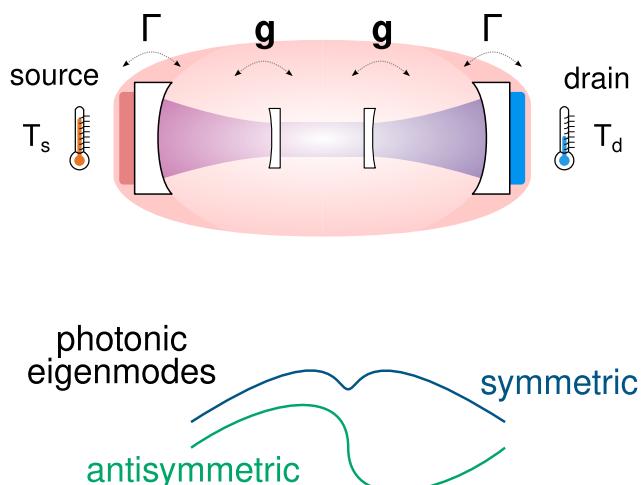
$Q = 20$

GLOBAL

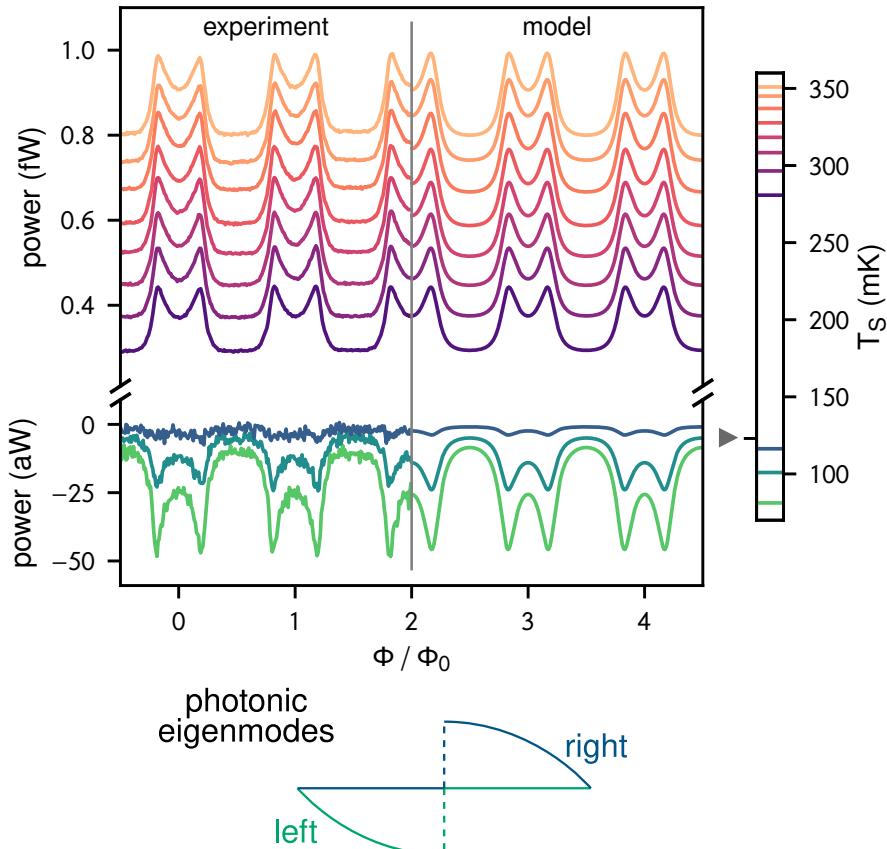


$g/\gamma = 0.4$

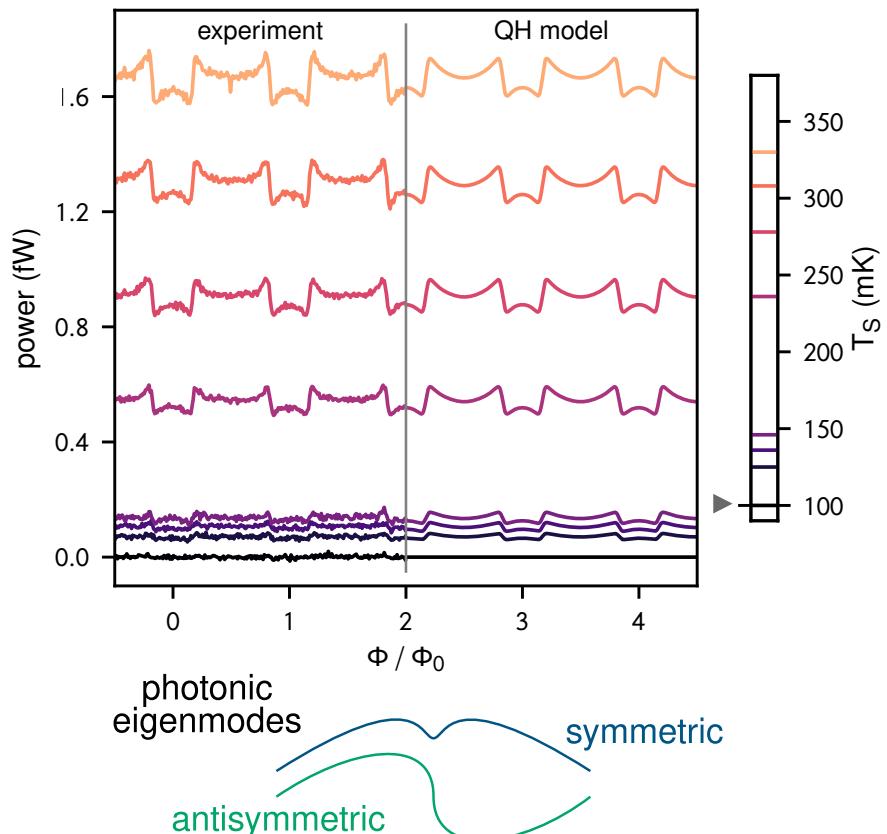
$Q = 20$
GLOBAL

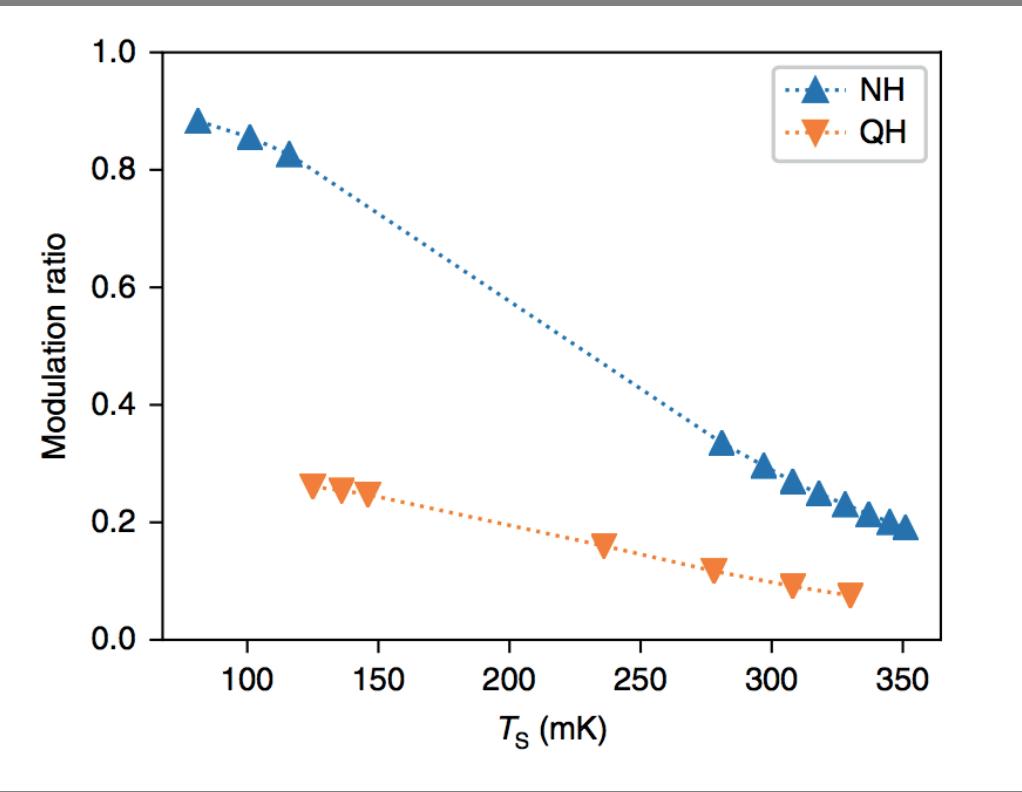


$g/\gamma = 0.05$

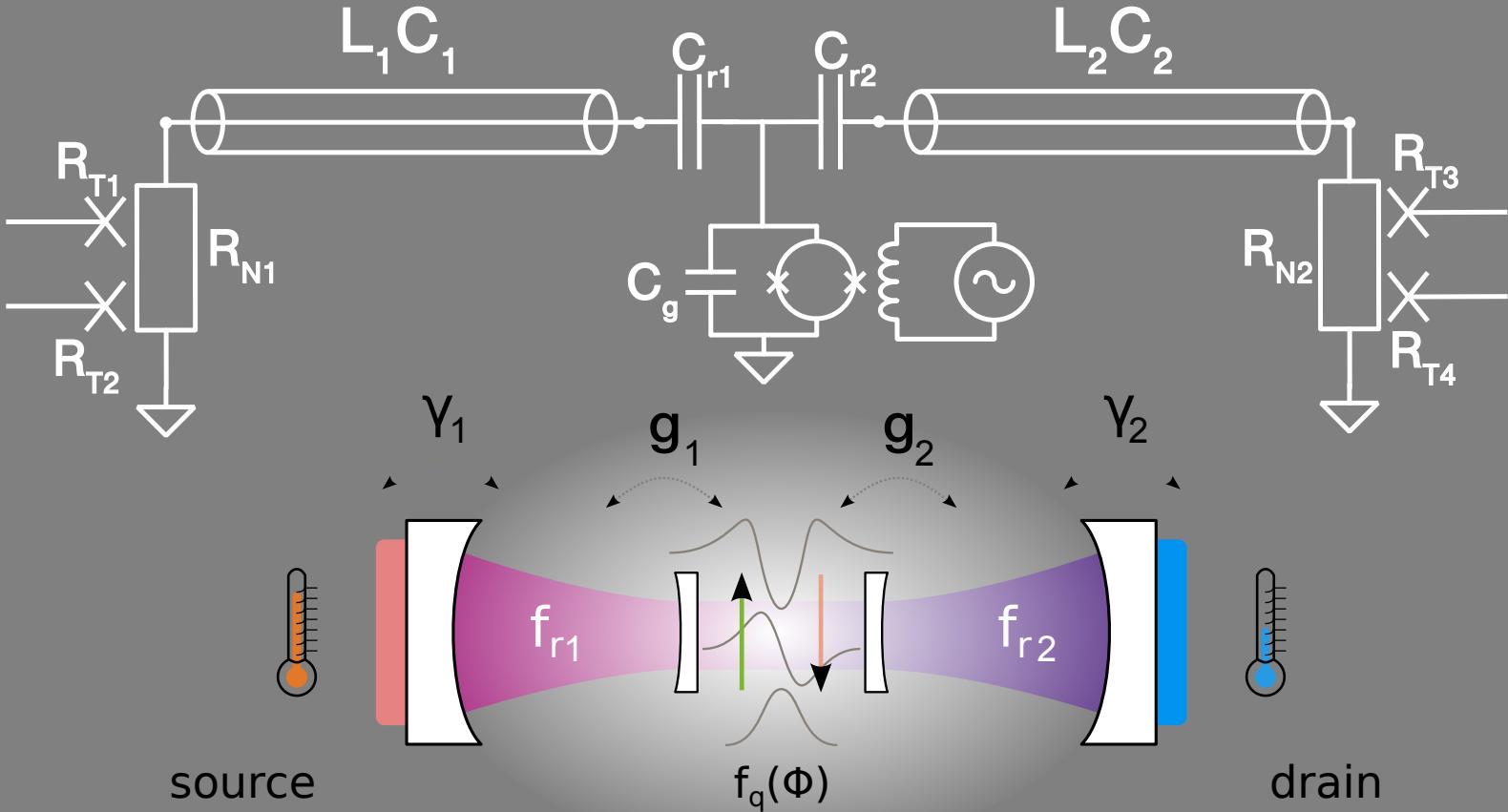


$g/\gamma = 0.4$

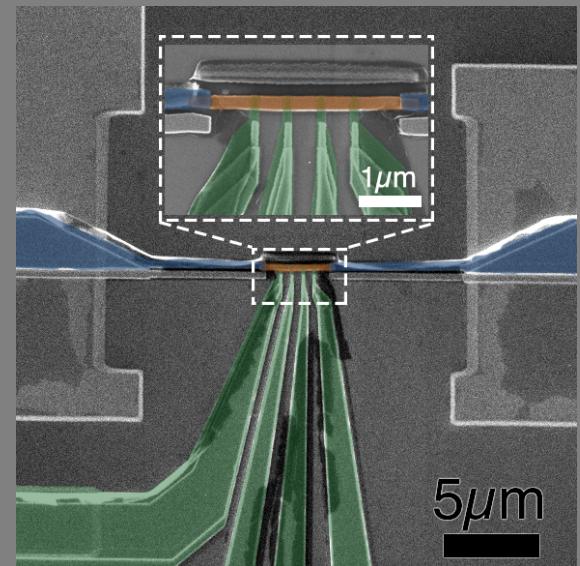
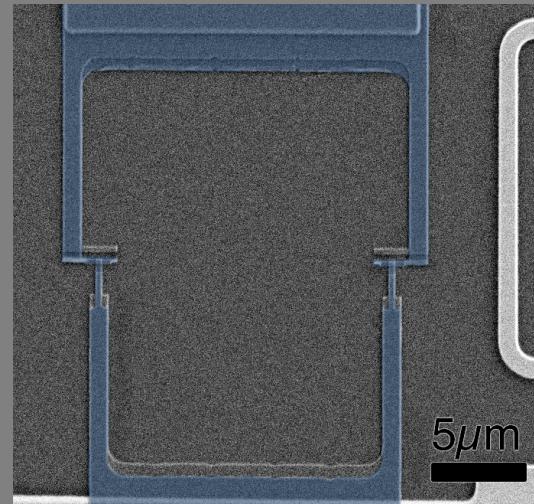
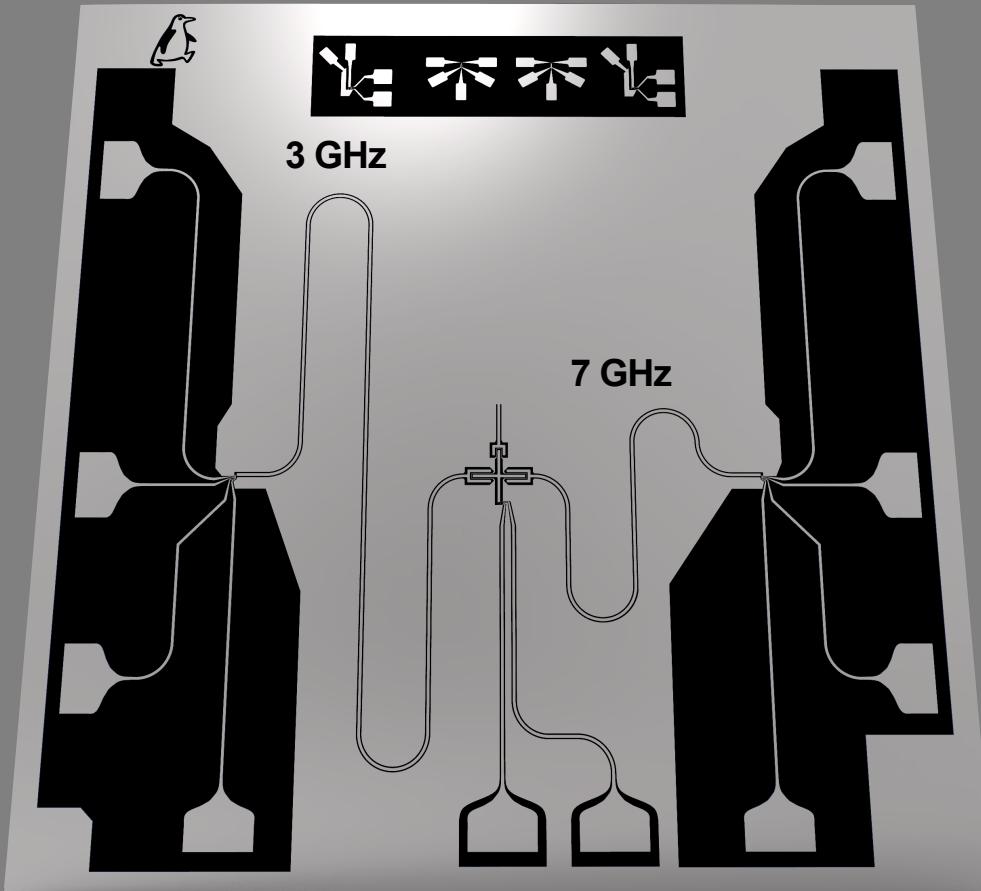


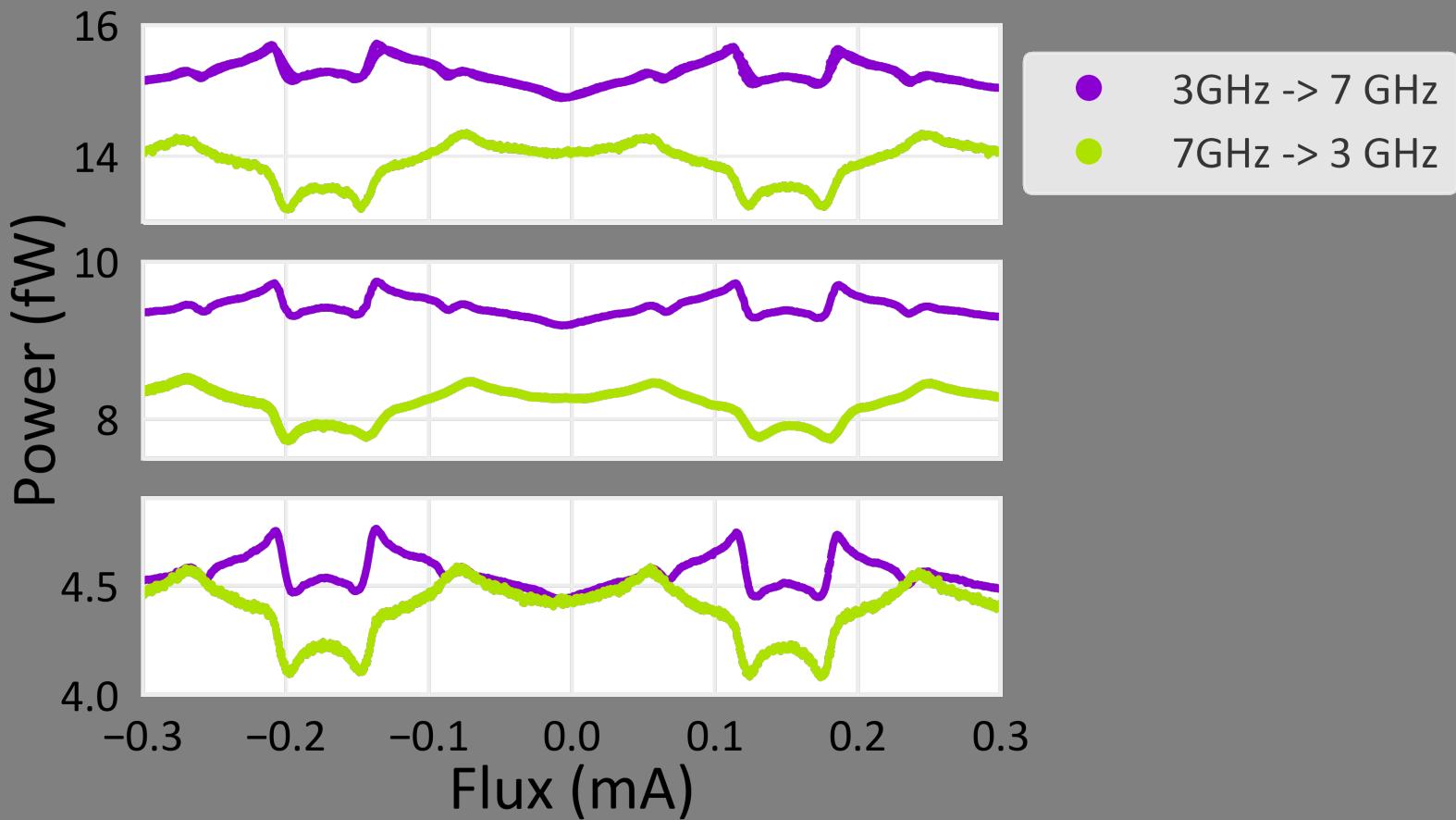


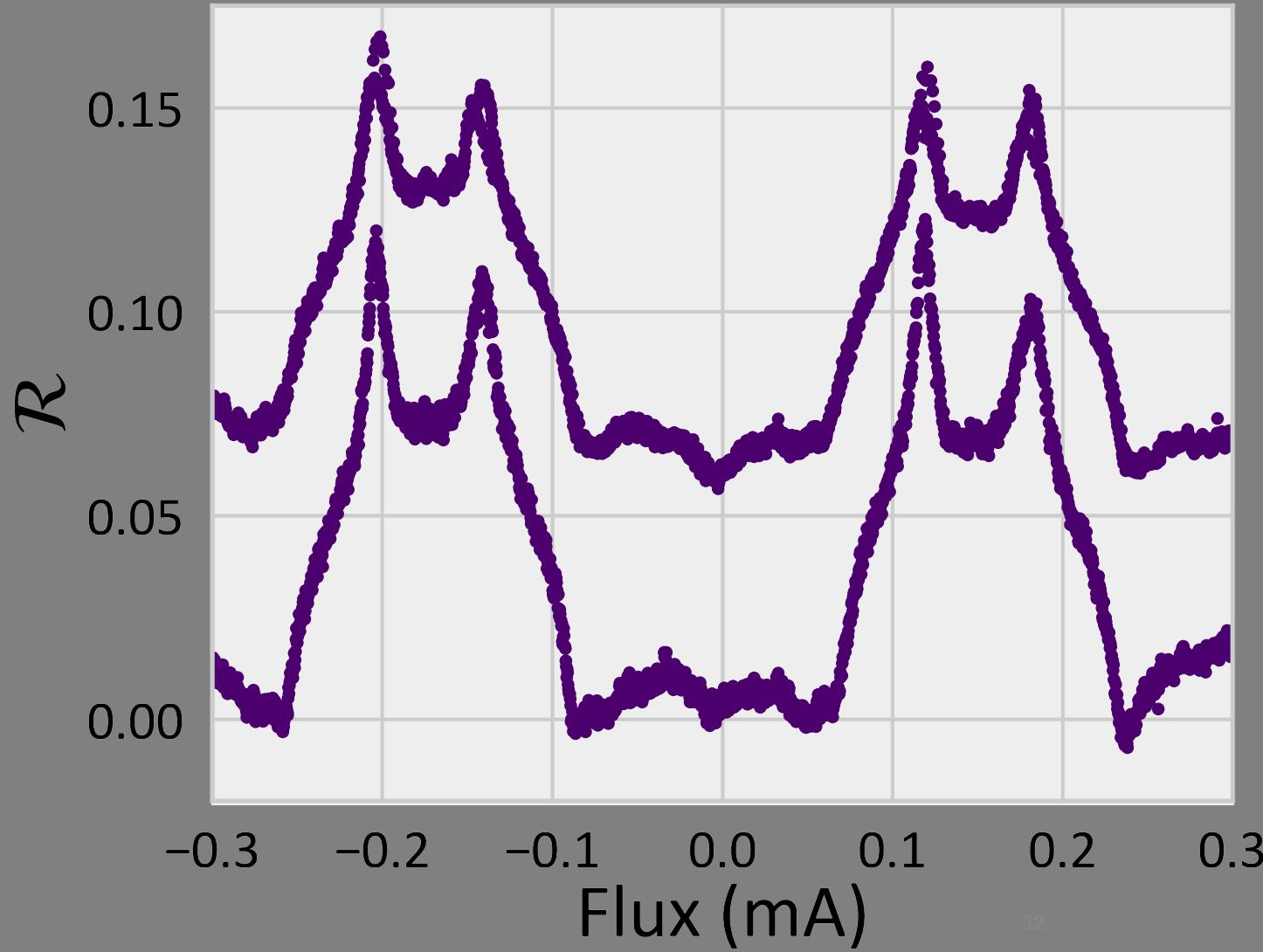
$$g/\gamma = 0.05$$
$$g/\gamma = 0.4$$



Artificial atom tunably coupled to two frequencies:
wireless thermal rectification







Key Messages:

Superconducting circuits are a fertile ground for investigating Quantum Thermodynamics (cQTD)

Coupling is important:
(Heisenberg cut)

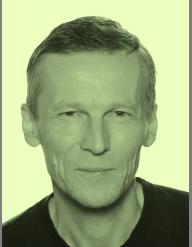
$g/\gamma \ll 1$
Local

$g/\gamma \approx 1$
Global

Wireless cooling is possible via a superconducting qubit coupled to two symmetric resonators

Wireless thermal rectification is achievable through a superconducting qubit coupled to two asymmetric resonators

Senior



Jukka Pekola



Dmitri Golubev



Joonas Peltonen

PostDocs



Azat Gubaydullin



Yu-Cheng Chang



Olivier Maillet



George Thomas



Alberto Ronzani
(VTT)



Olli-Pentti Saira
(Brookhaven)

PhD Students



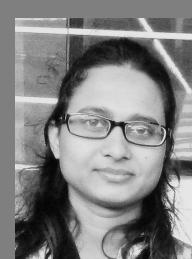
Jorden Senior



Bayan Karimi



Brecht Donvil
(University of Helsinki)



Shilpi Singh



Elsa Mannila



Marco Marín
Suárez



Klaara Viisanen



Libin Wang



Rishabh Upadhyay

Jorden Senior



A!

Aalto University

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