

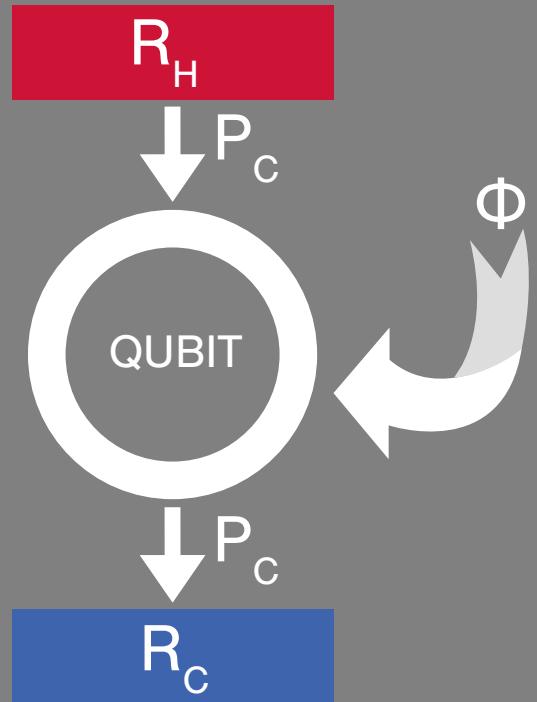


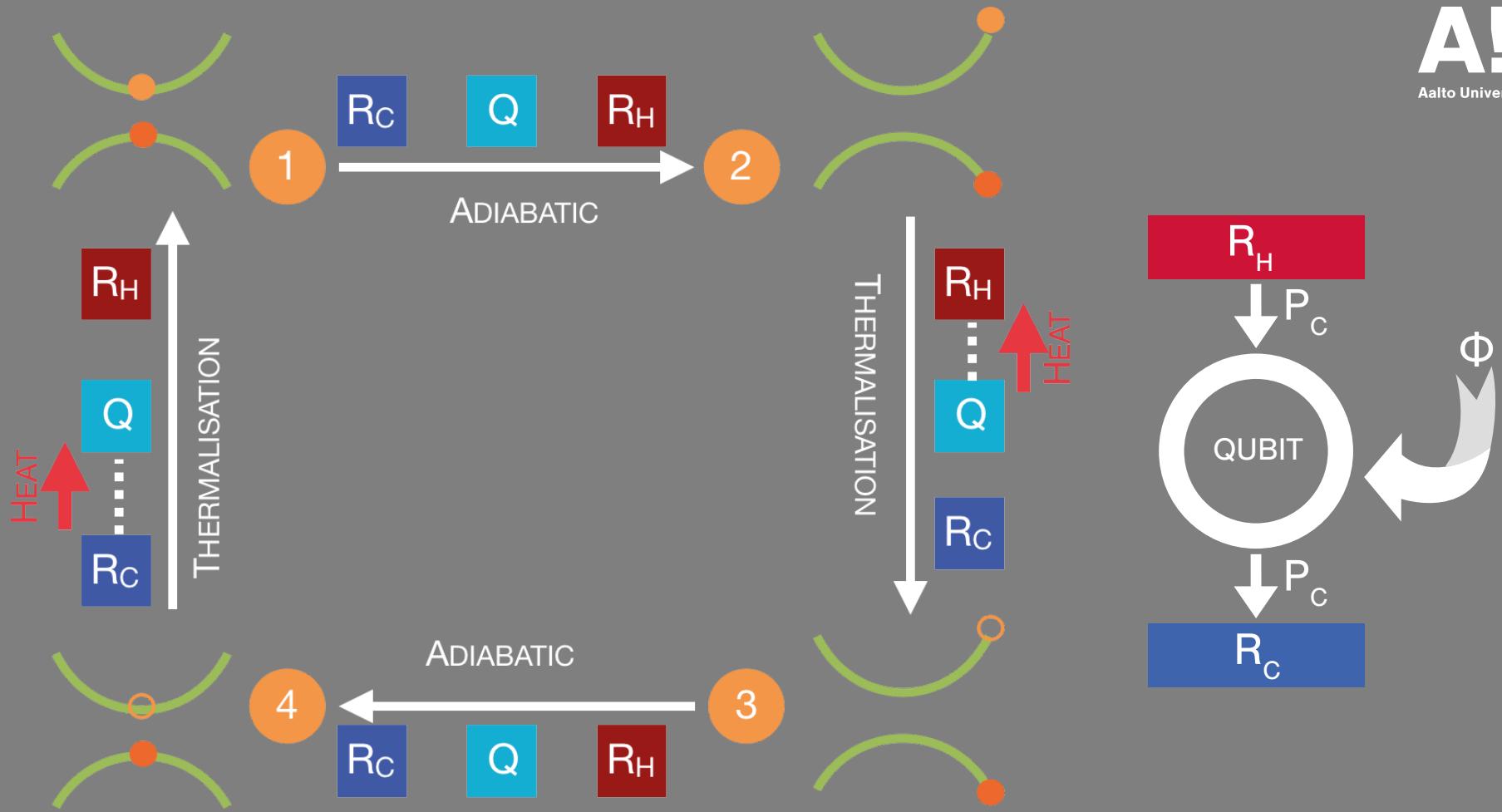
A!  
Aalto University

# Quantum Thermodynamics with Superconducting Circuits

*APS March Meeting, Boston 2019*

# Towards a Quantum Heat Engine



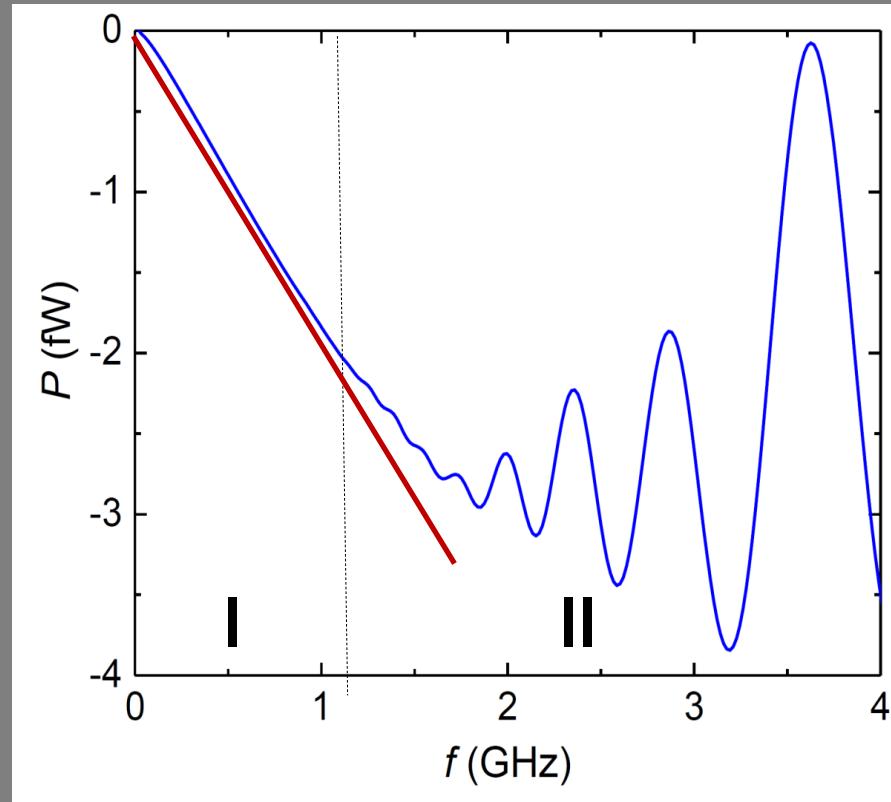


A. Niskanen, Y. Nakamura, J. Pekola, PRB 76, 174523 (2007)  
 B. Karimi and J. Pekola, PRB 94, 184503 (2016)

# Quantum heat engine (quantum Otto refrigerator)

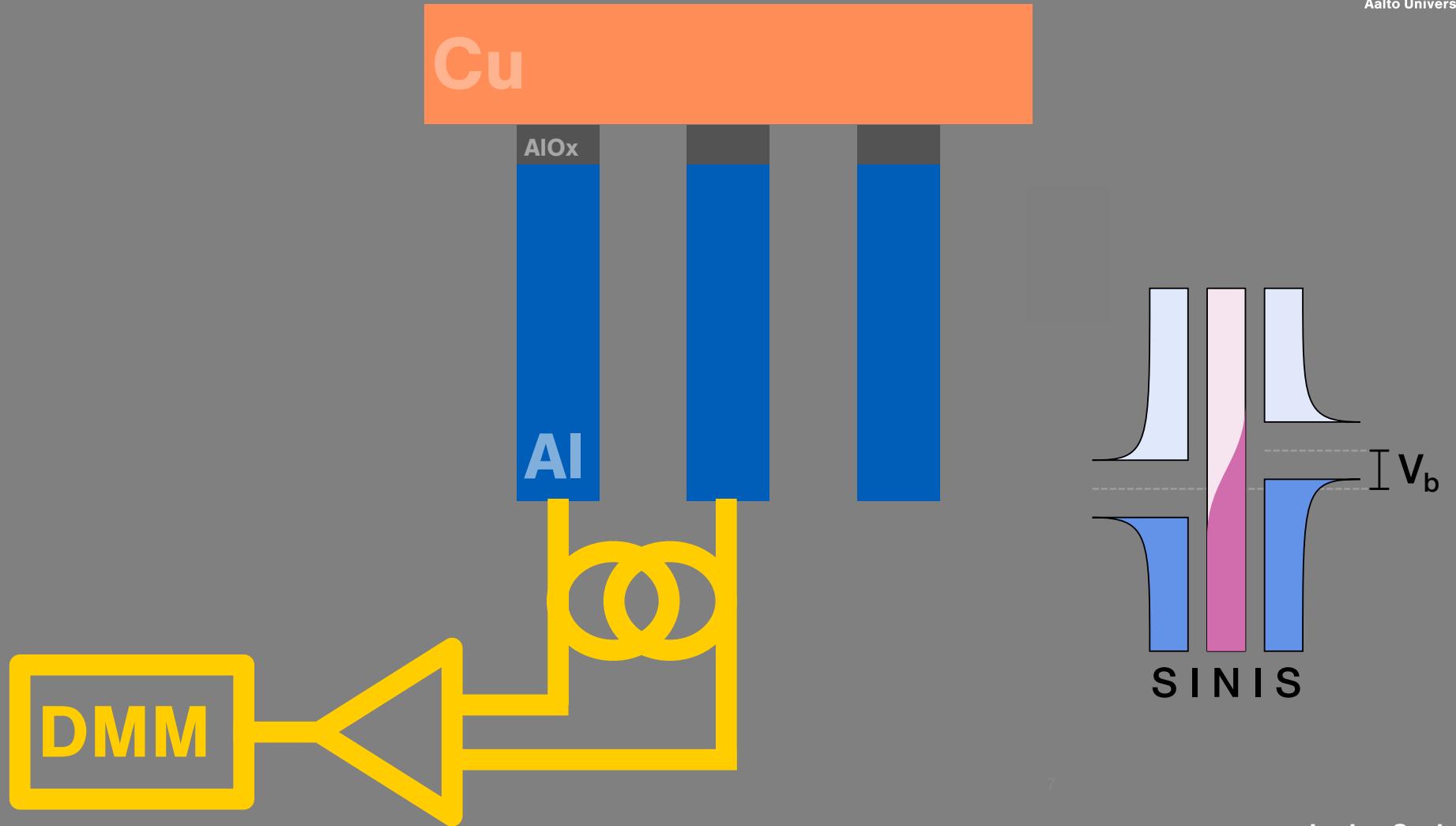
Different operation regimes:

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

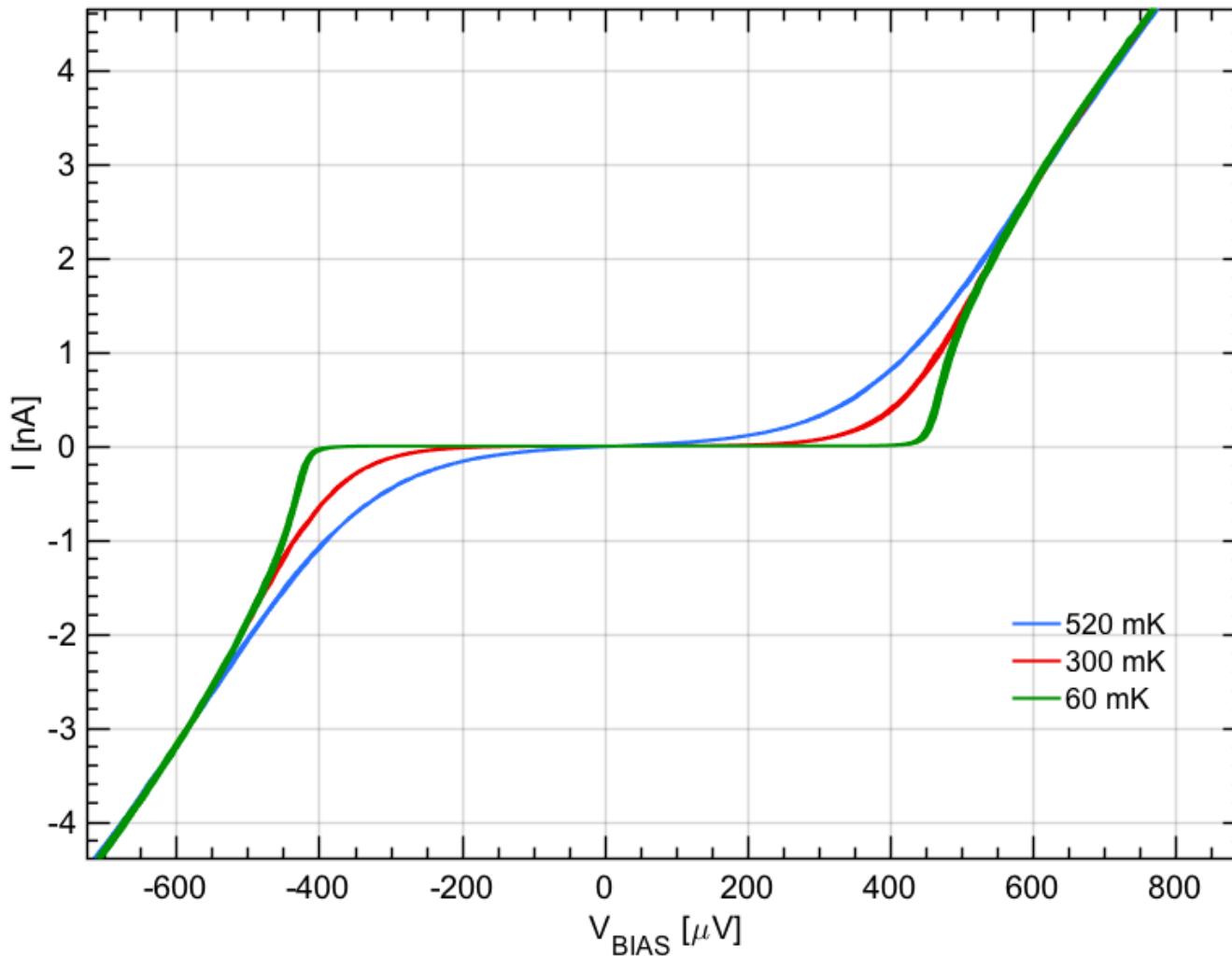


Let's build our  
circuit...

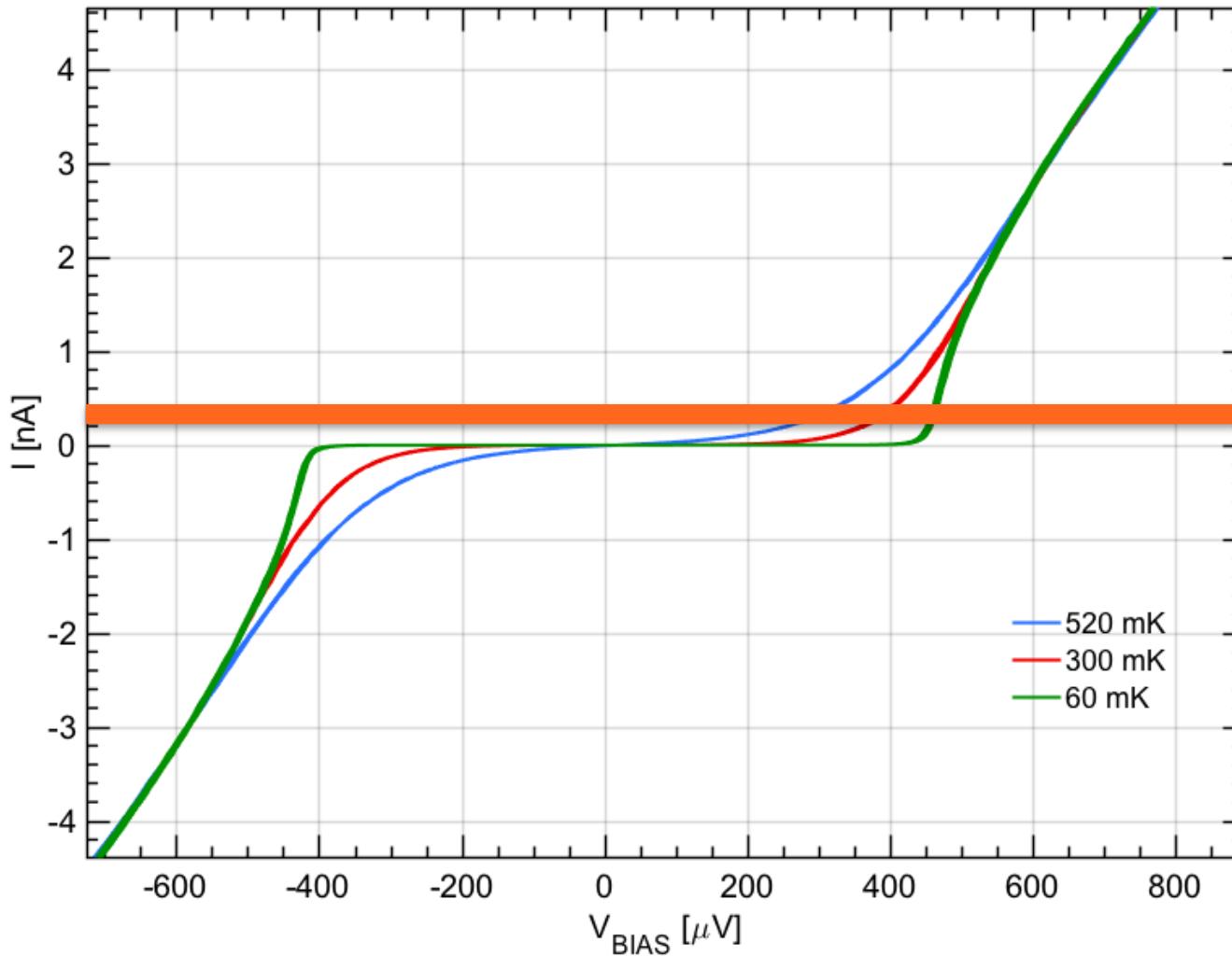
Cu

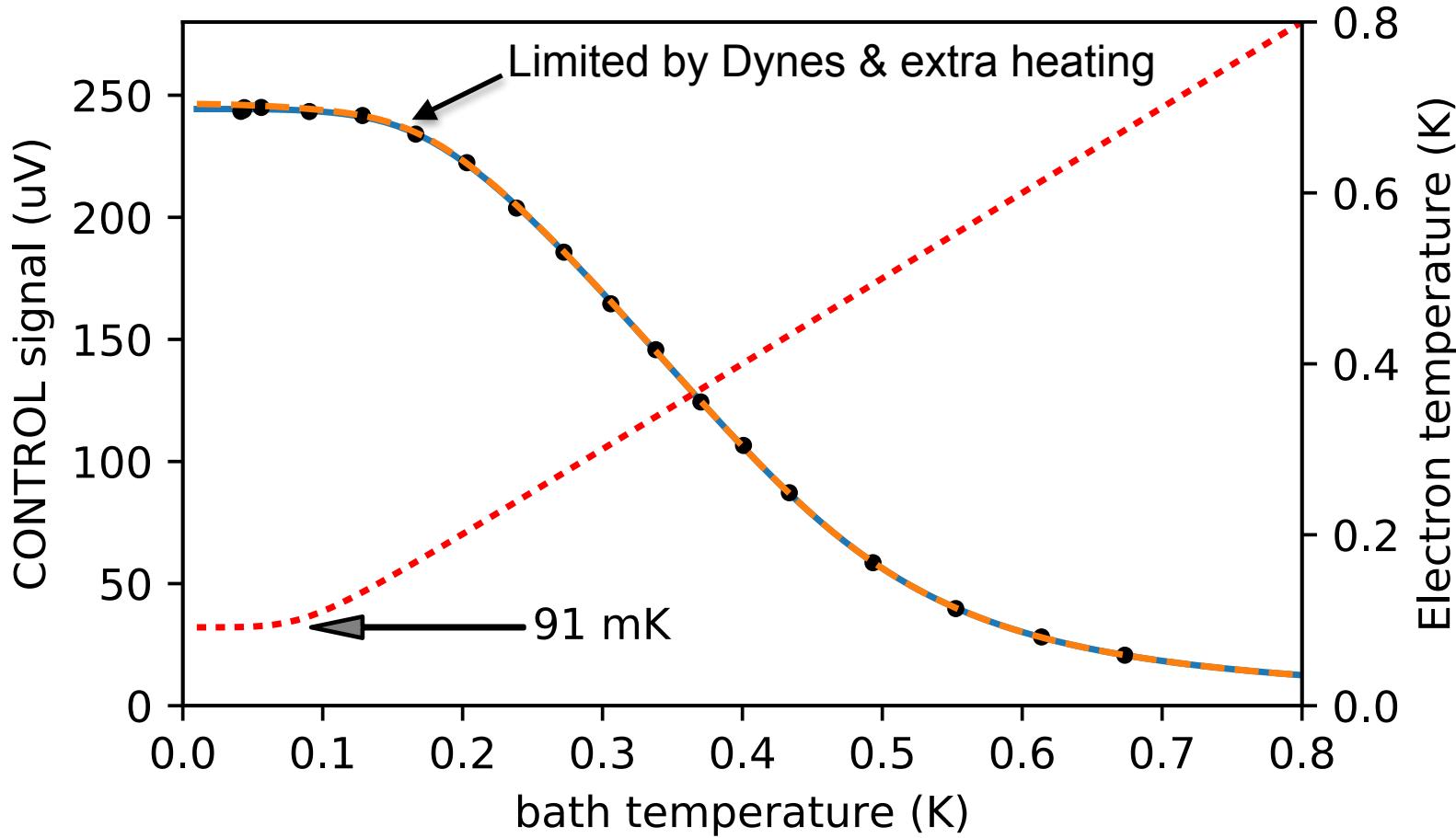


### Temperature Sweep, Junctions A and B



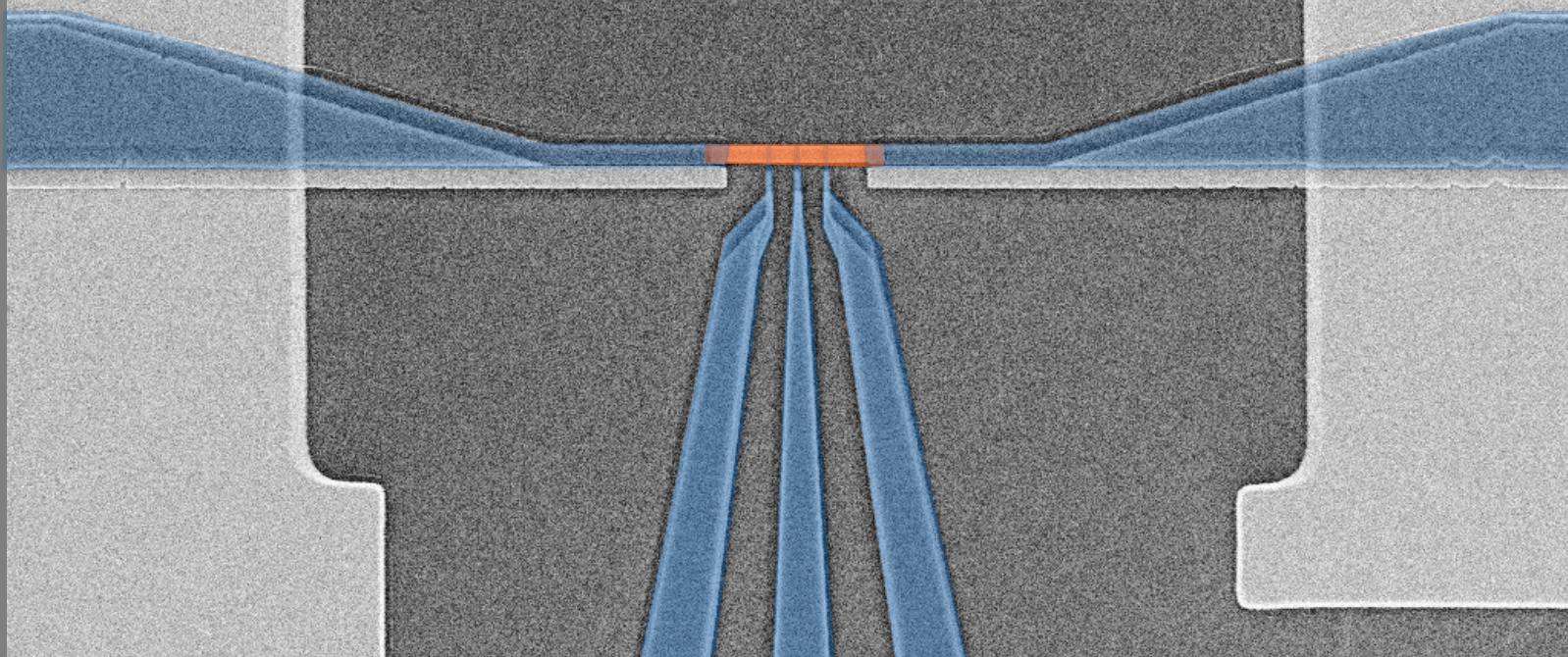
### Temperature Sweep, Junctions A and B

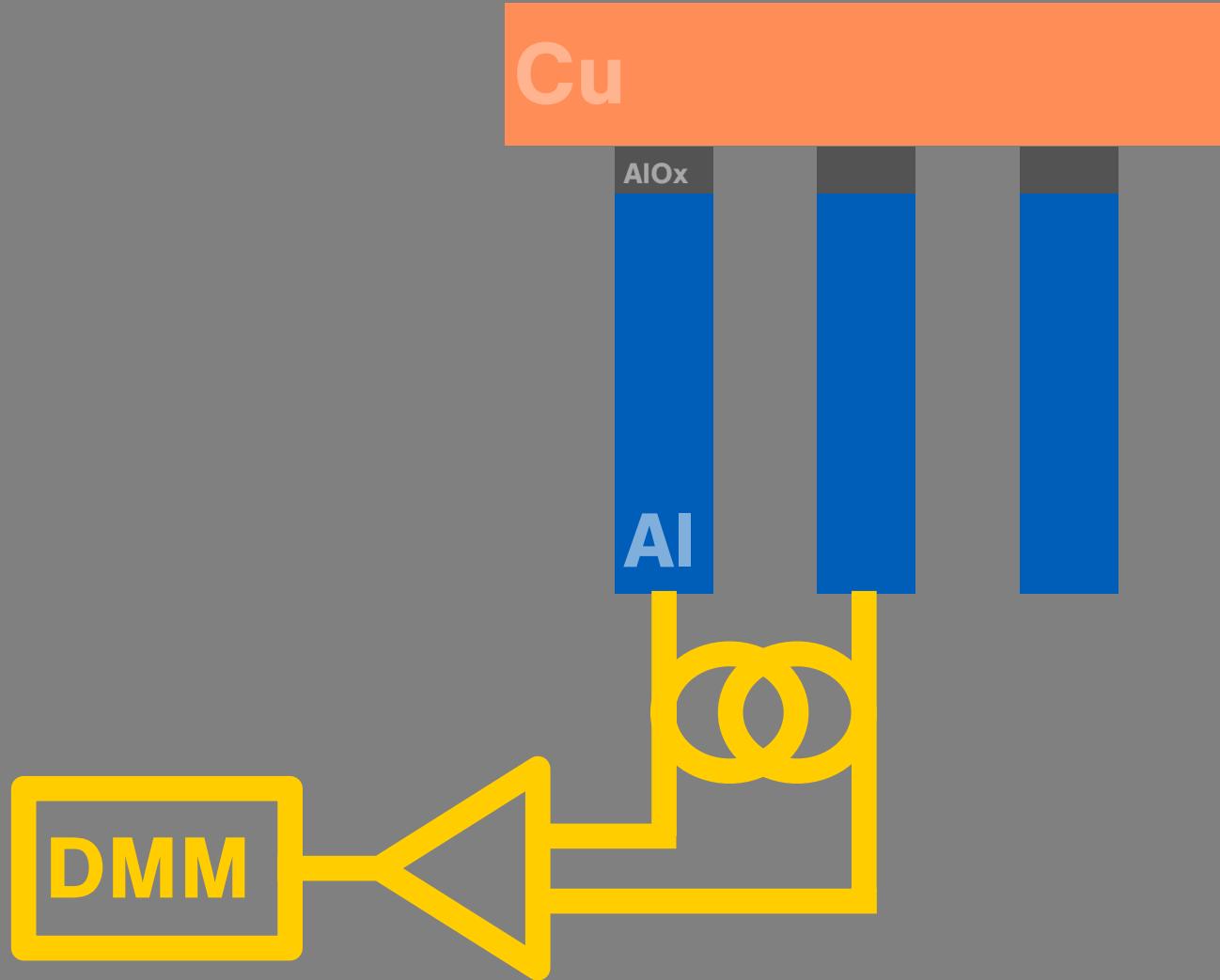


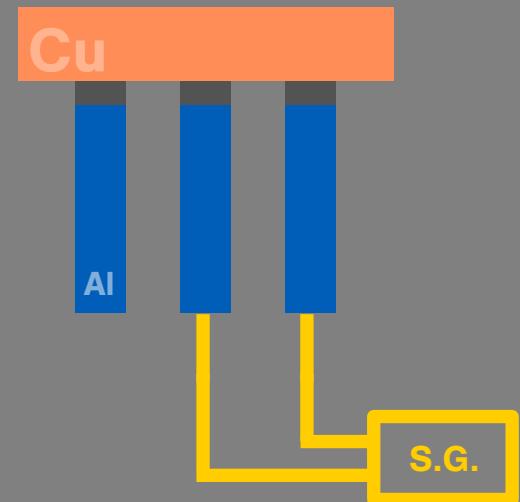
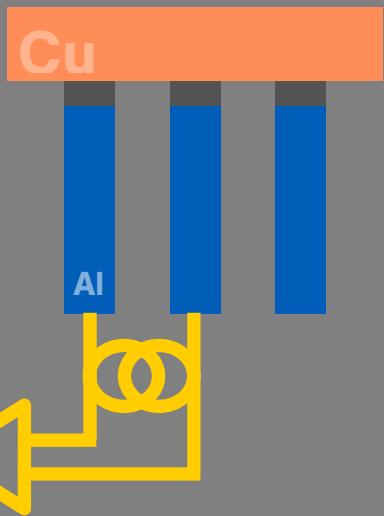


**Ground**

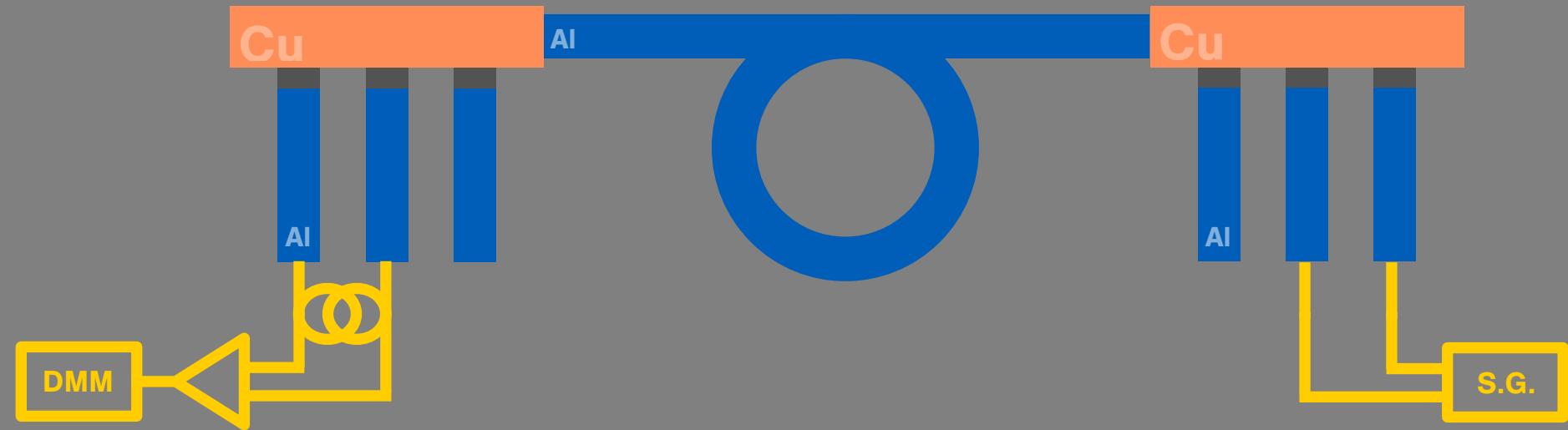
**CPW**







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

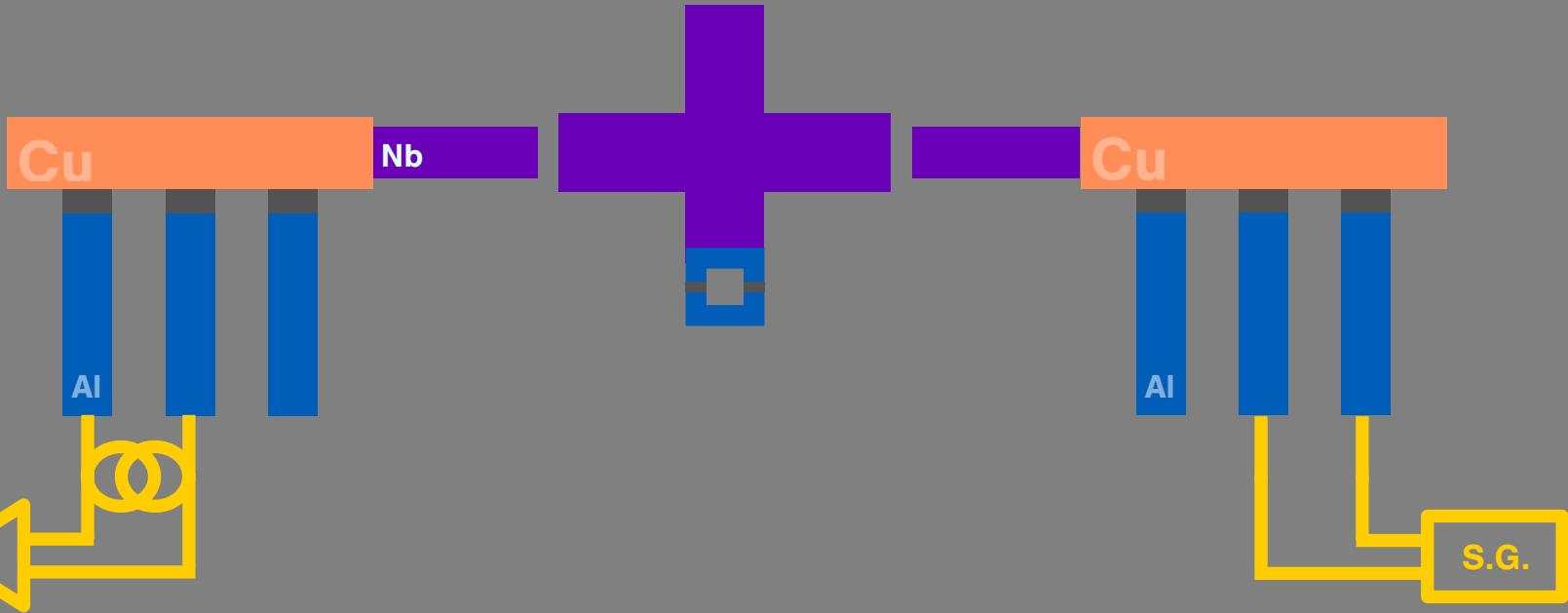


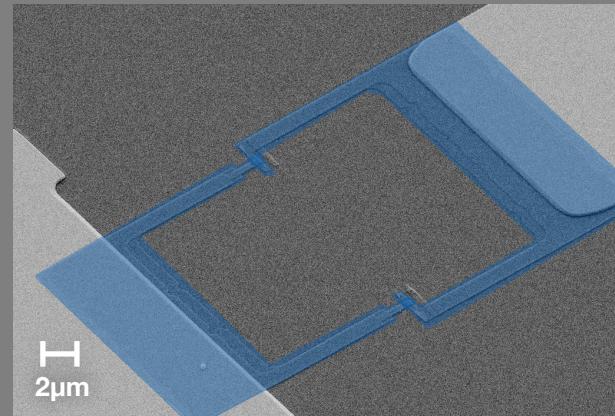
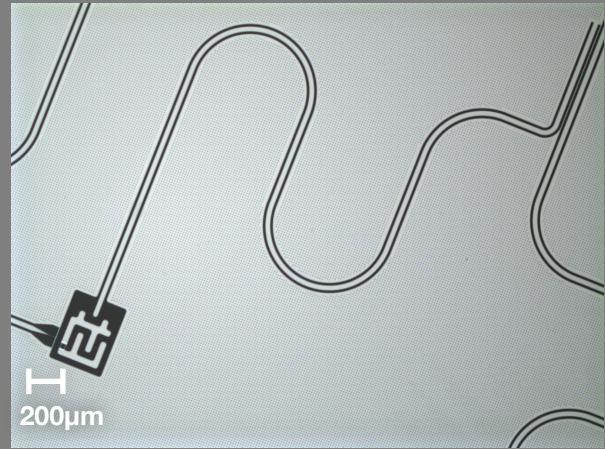
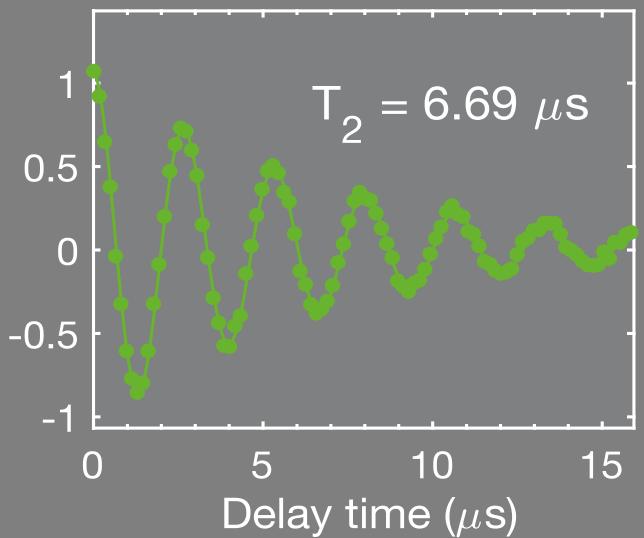
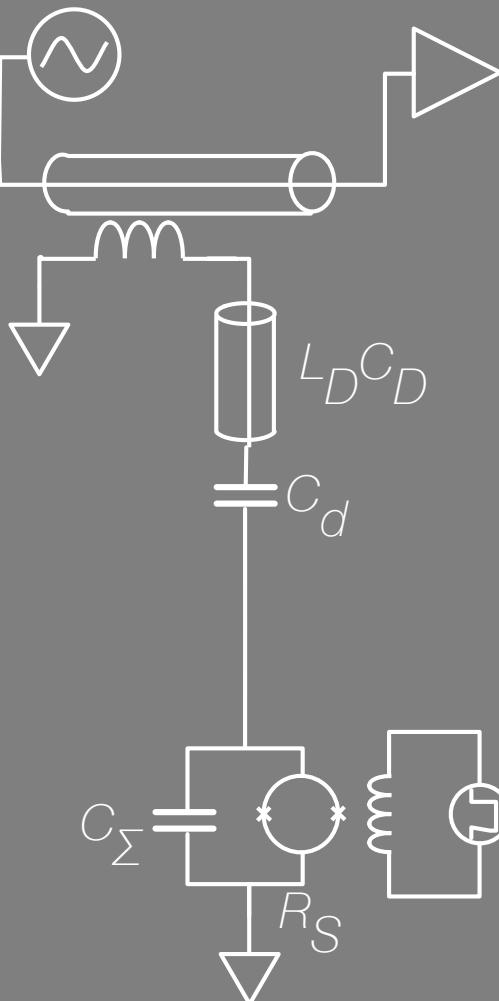
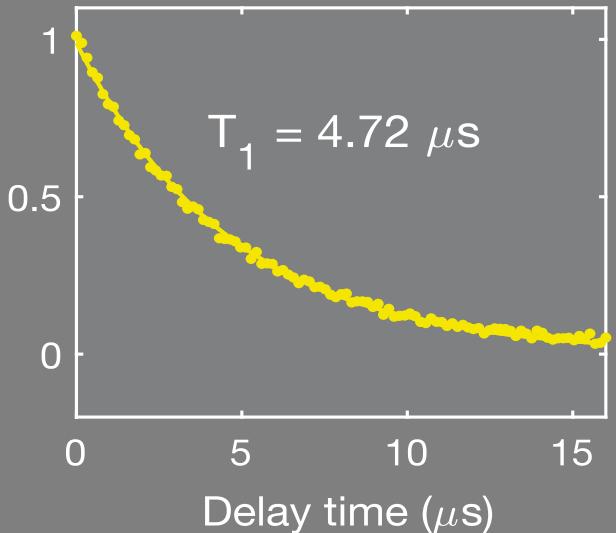
### Photonic Heat Transport:

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

### 'Quantum' of Heat Transport

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

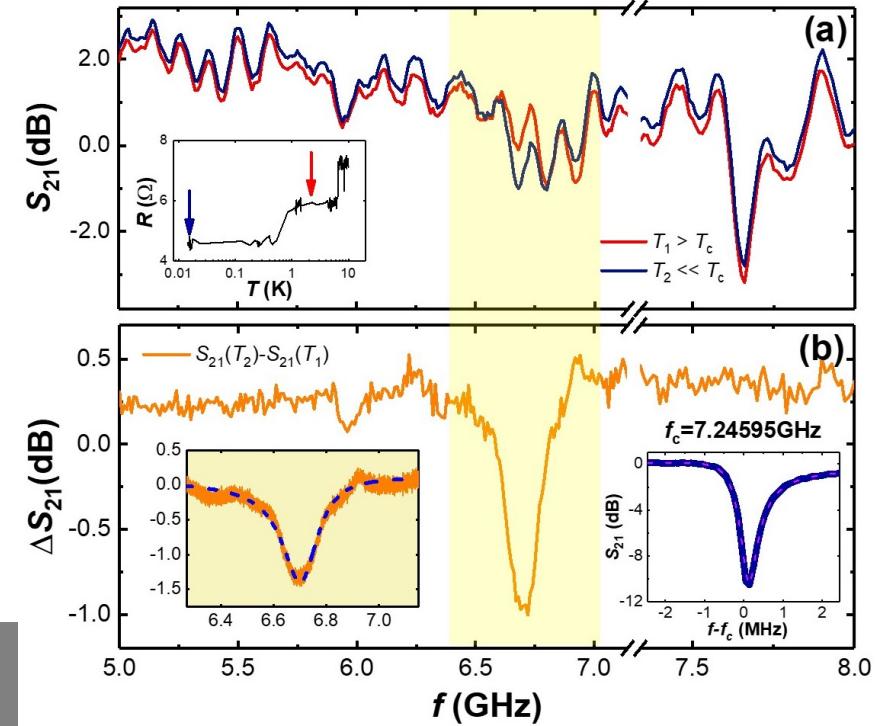
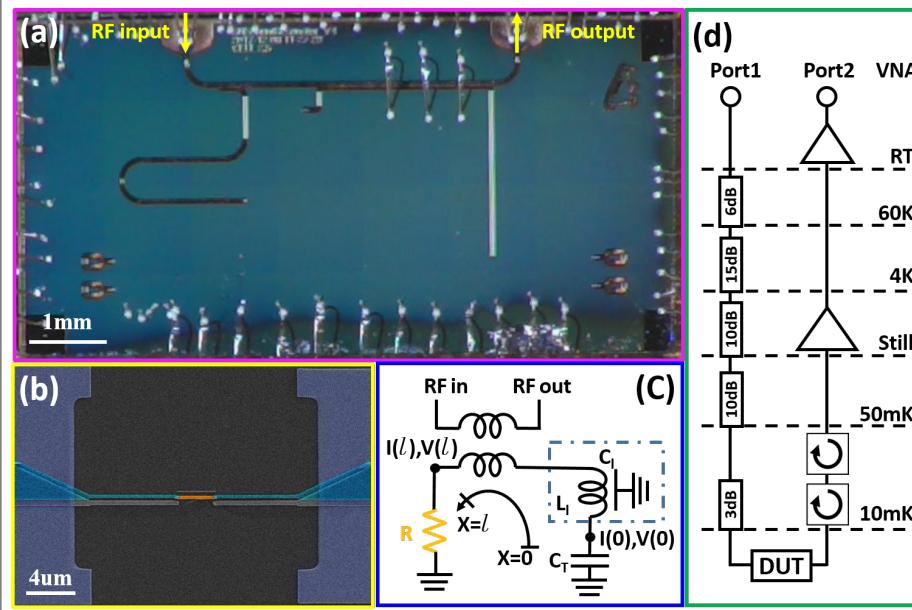




R. George, JS, et al, JLTP (2017)

Jorden Senior

# What happens to Q of the resistively shunted resonators?



$Q \approx 4 - 20$

# Half-way summary:

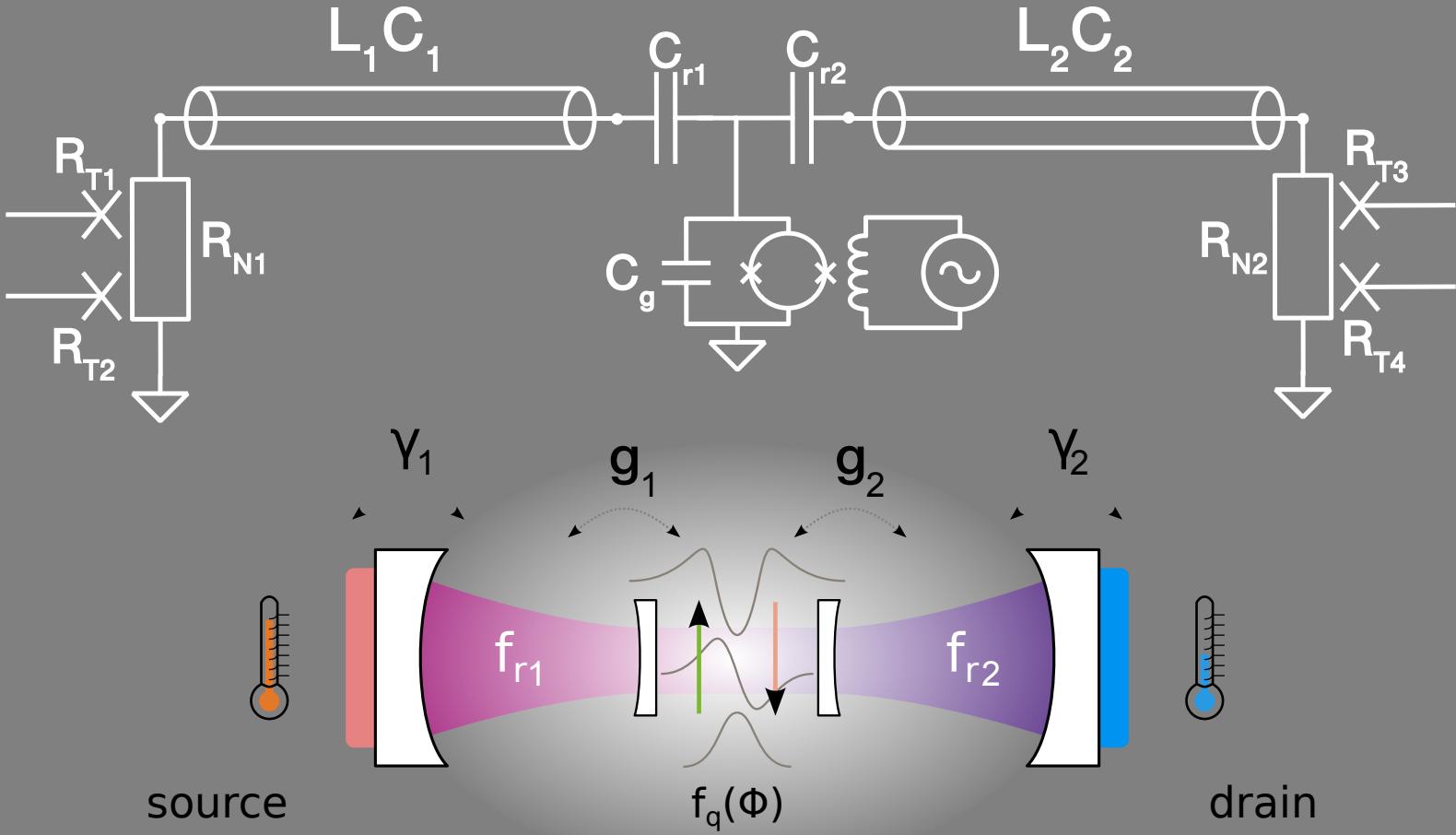
The goal is to develop a platform for looking at thermodynamics in an open quantum system (Otto engine)

We have our components:

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

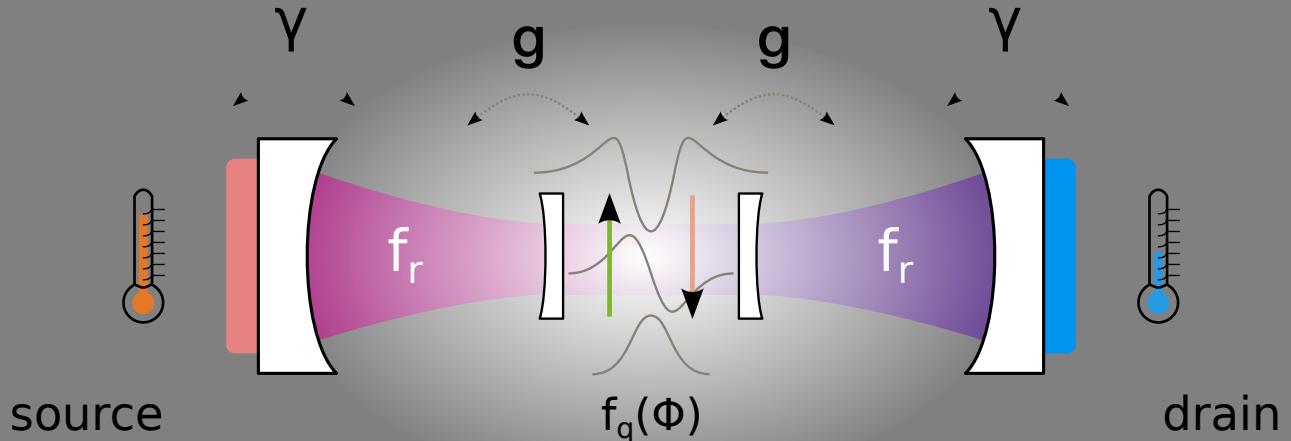
In Part II, let's put them all together to make a

Quantum Heat Valve

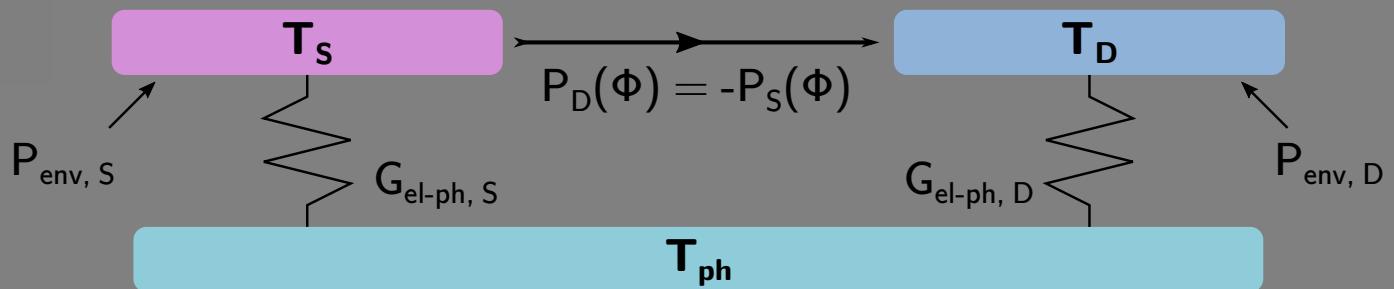


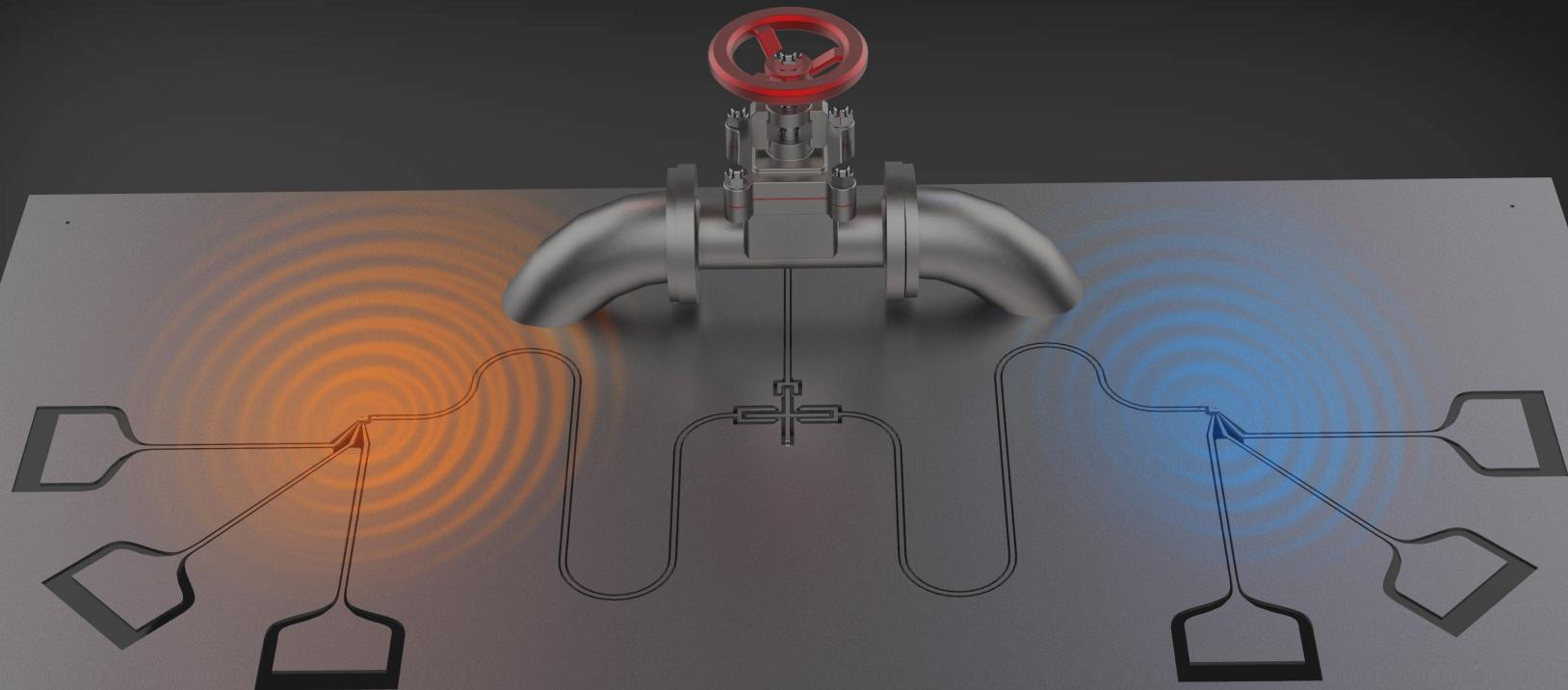
Large parameter space!

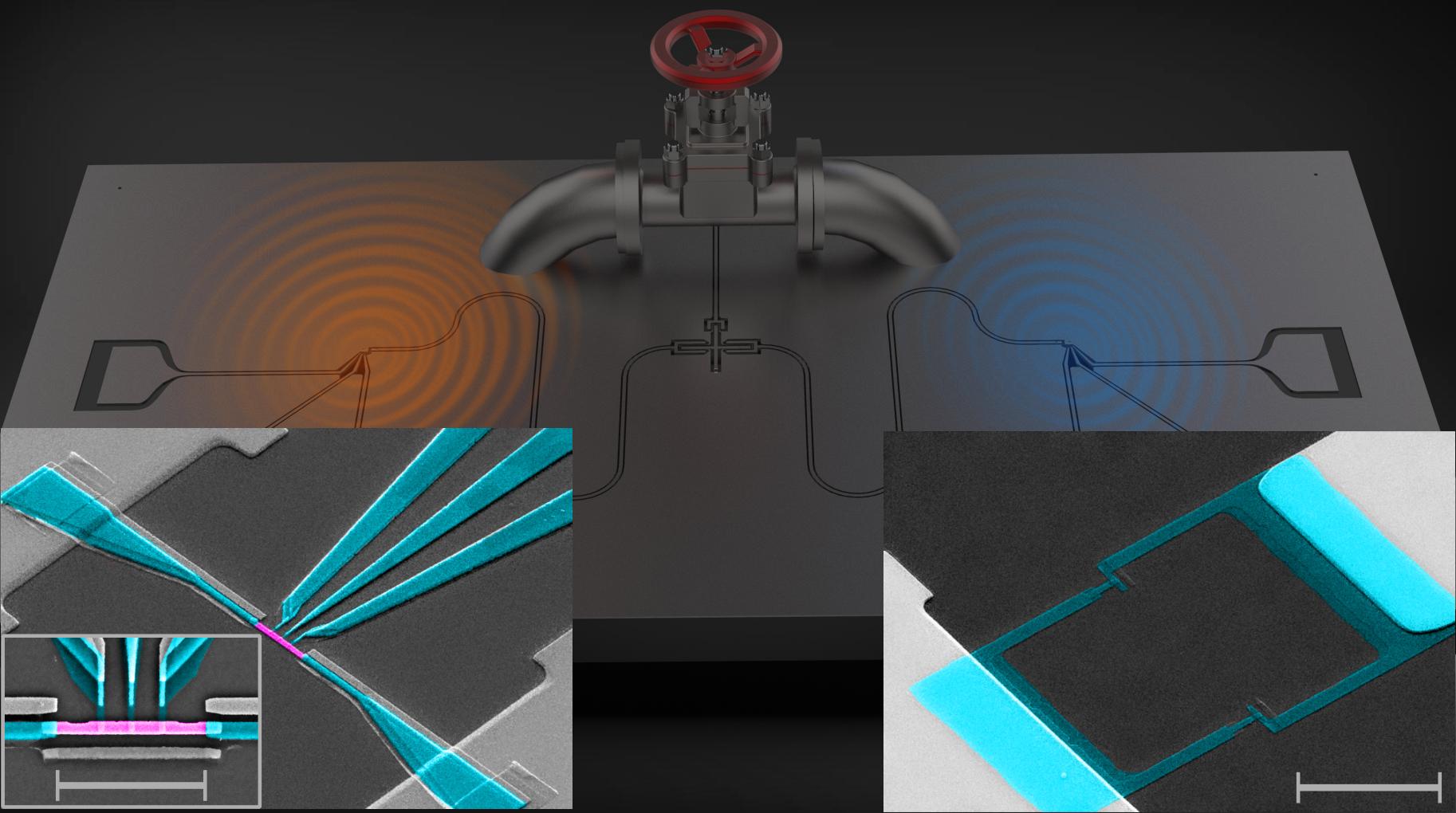
19

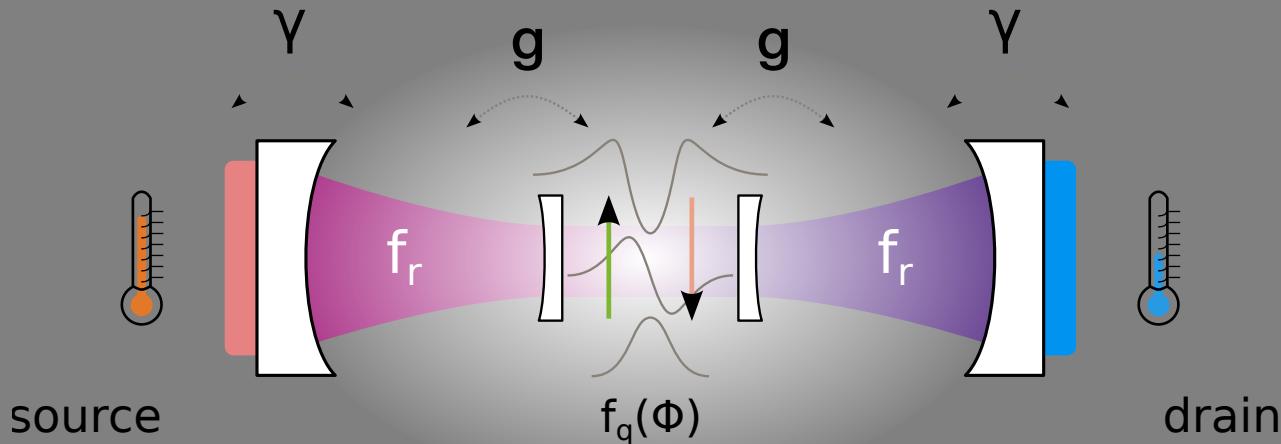


$$f_{r1} = f_{r2}$$







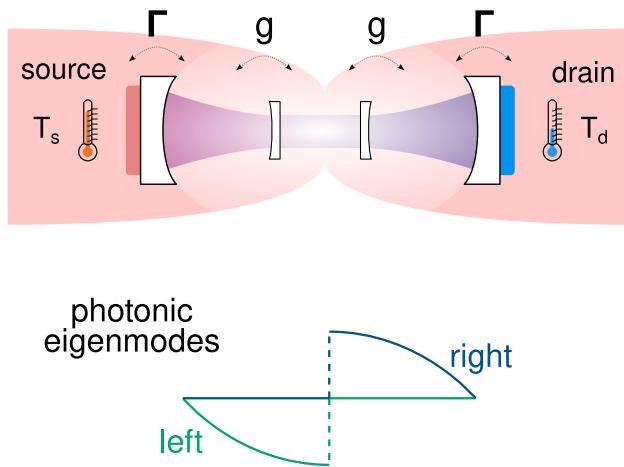


$g/\gamma = 0.05$   
 $Q = 3$   
**LOCAL**

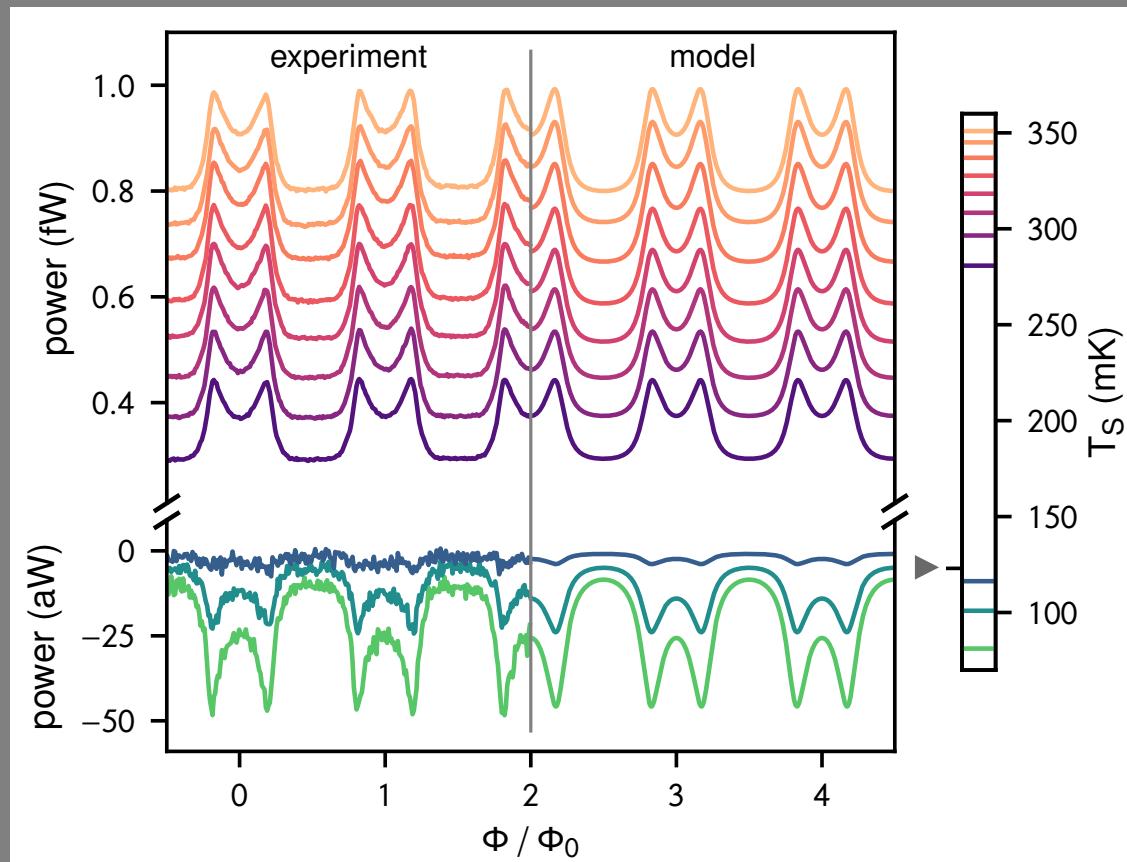
$g/\gamma = 0.4$   
 $Q = 20$   
**GLOBAL**

$g/\gamma = 0.05$

$Q = 3$   
LOCAL



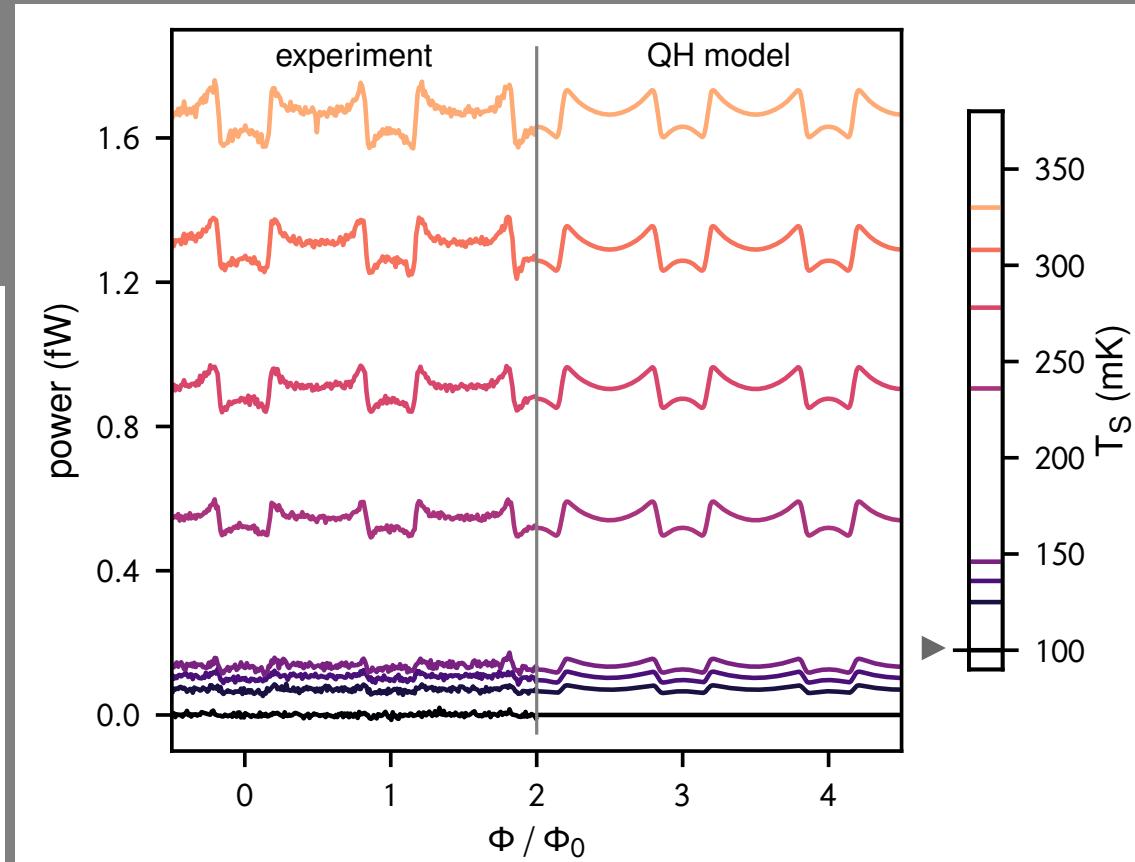
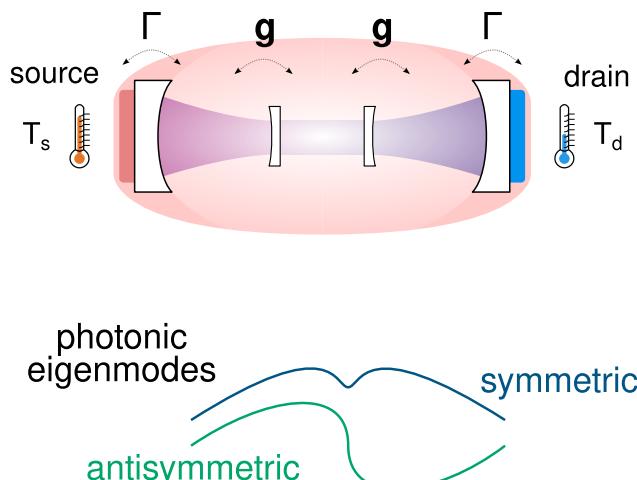
NEP  $\sim 5$  aW  
'wireless' cooling (4mm) of 50aW



$g/\gamma = 0.4$

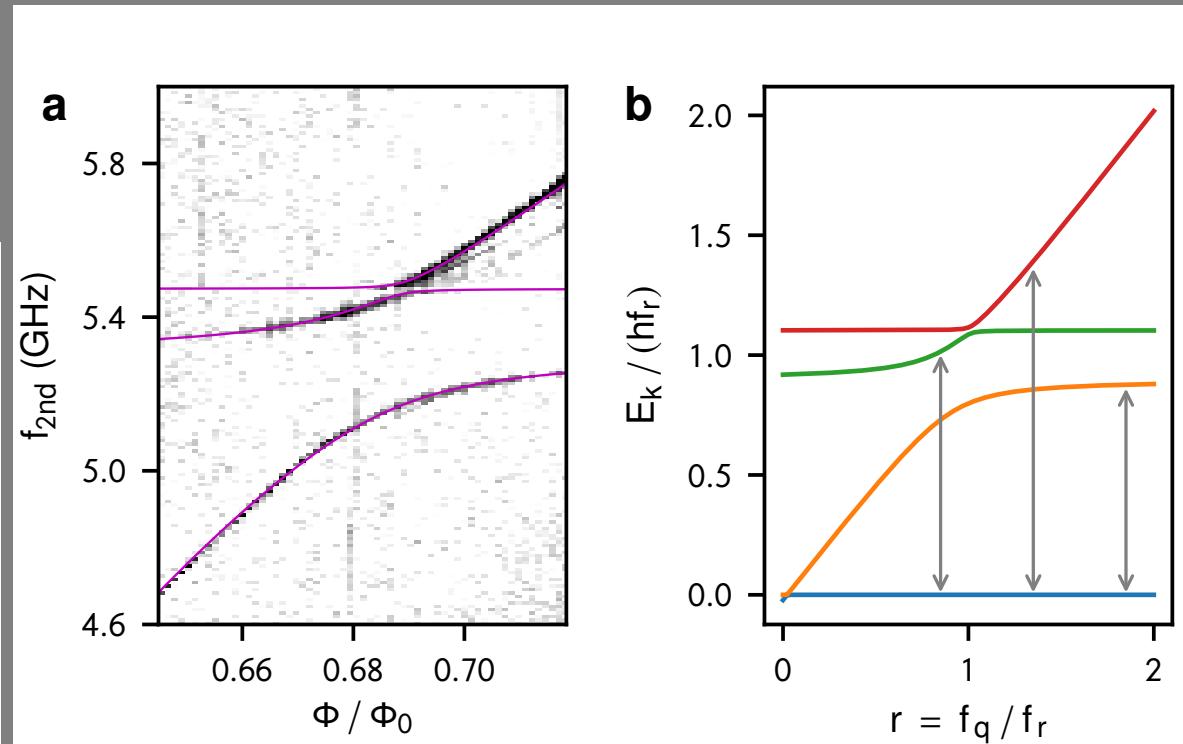
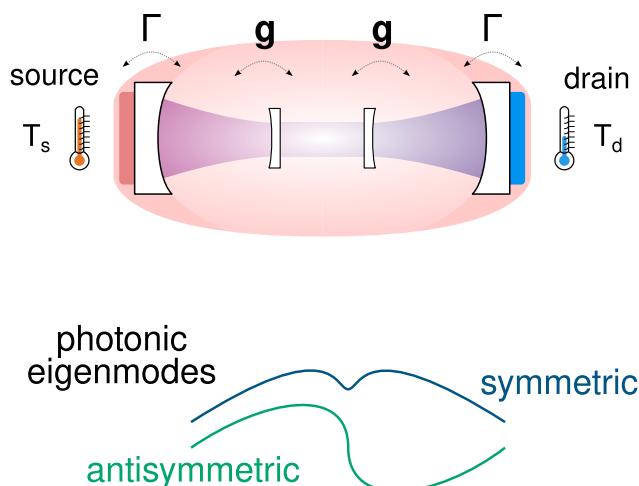
$Q = 20$

**GLOBAL**

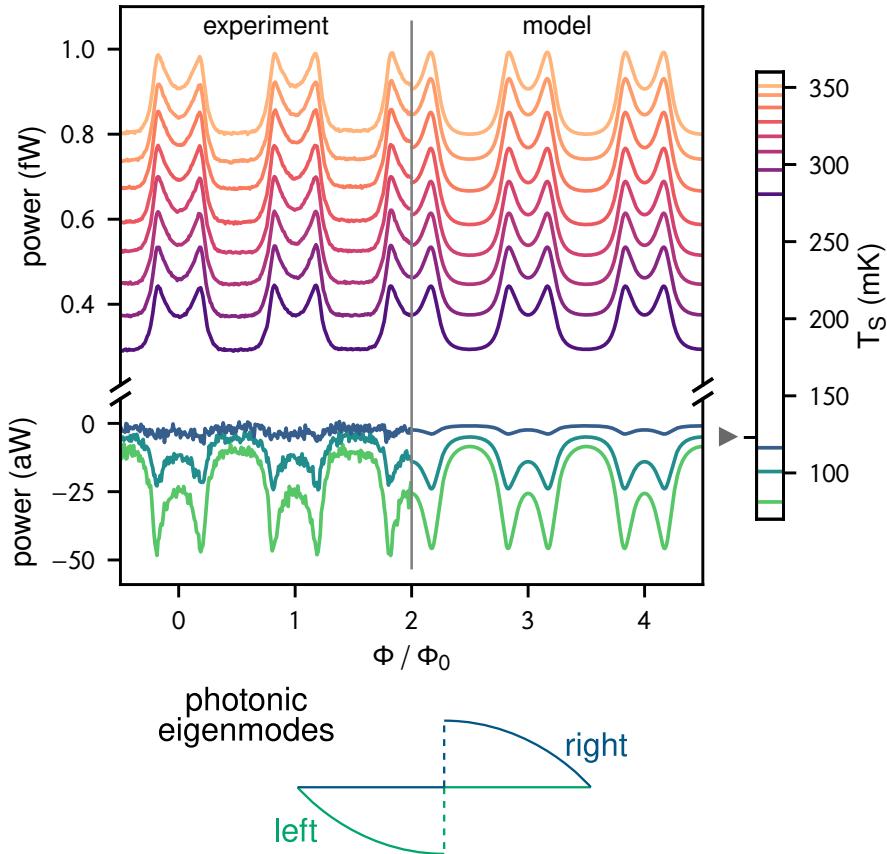


$g/\gamma = 0.4$

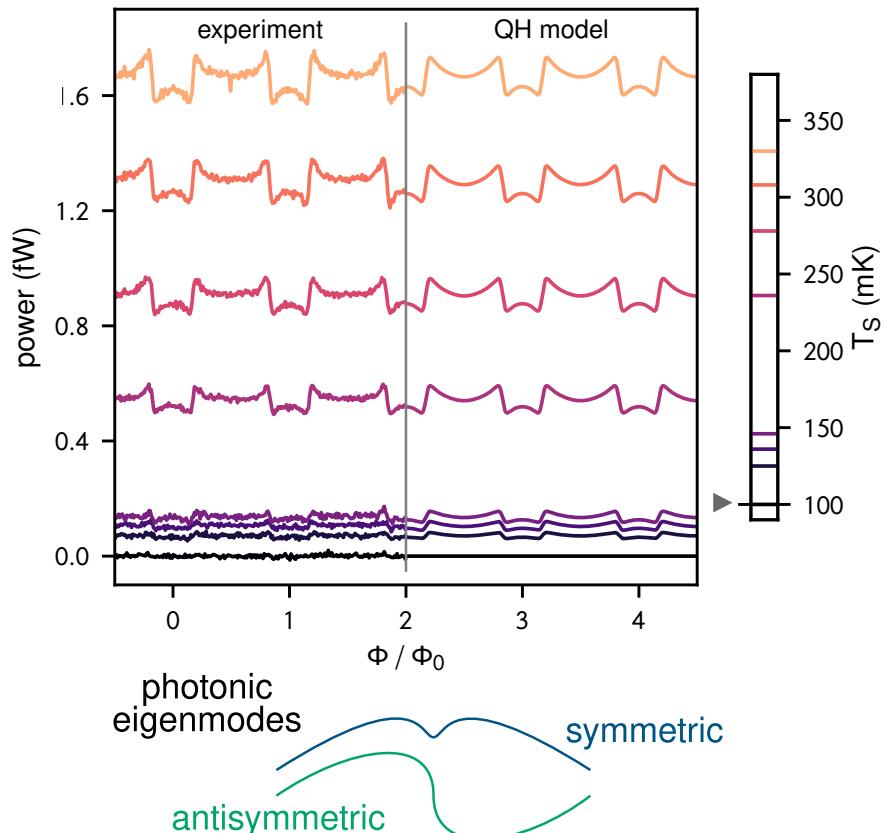
$Q = 20$   
**GLOBAL**

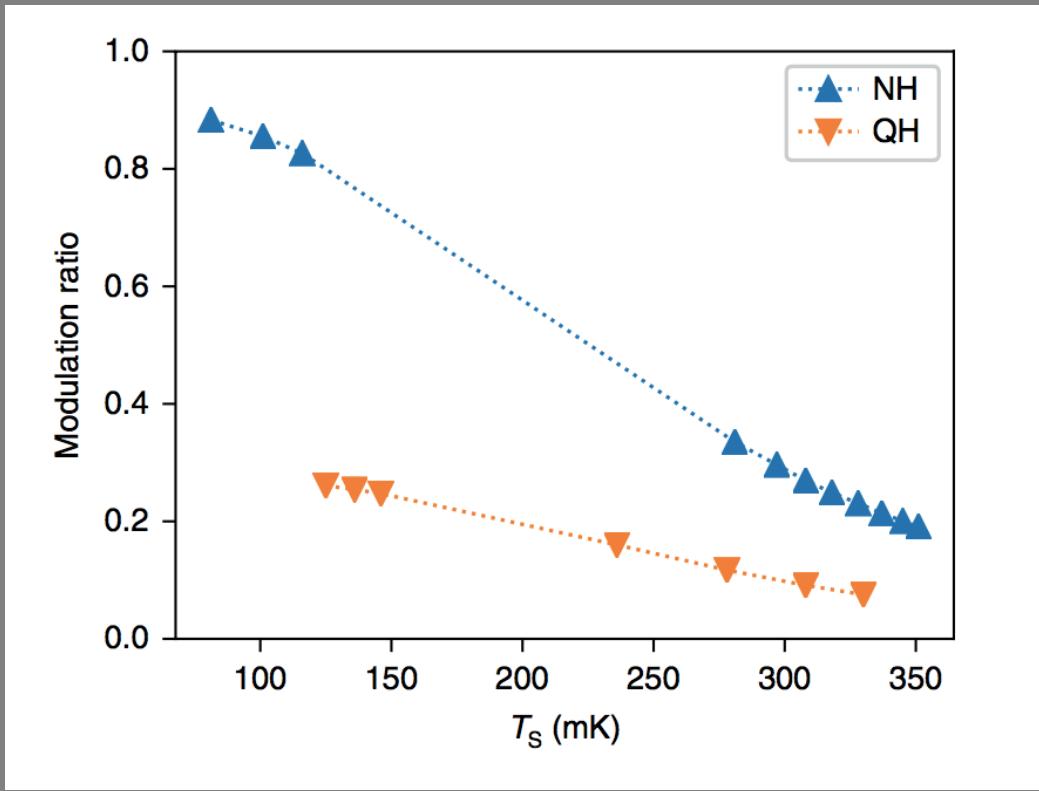


# $g/\gamma = 0.05$

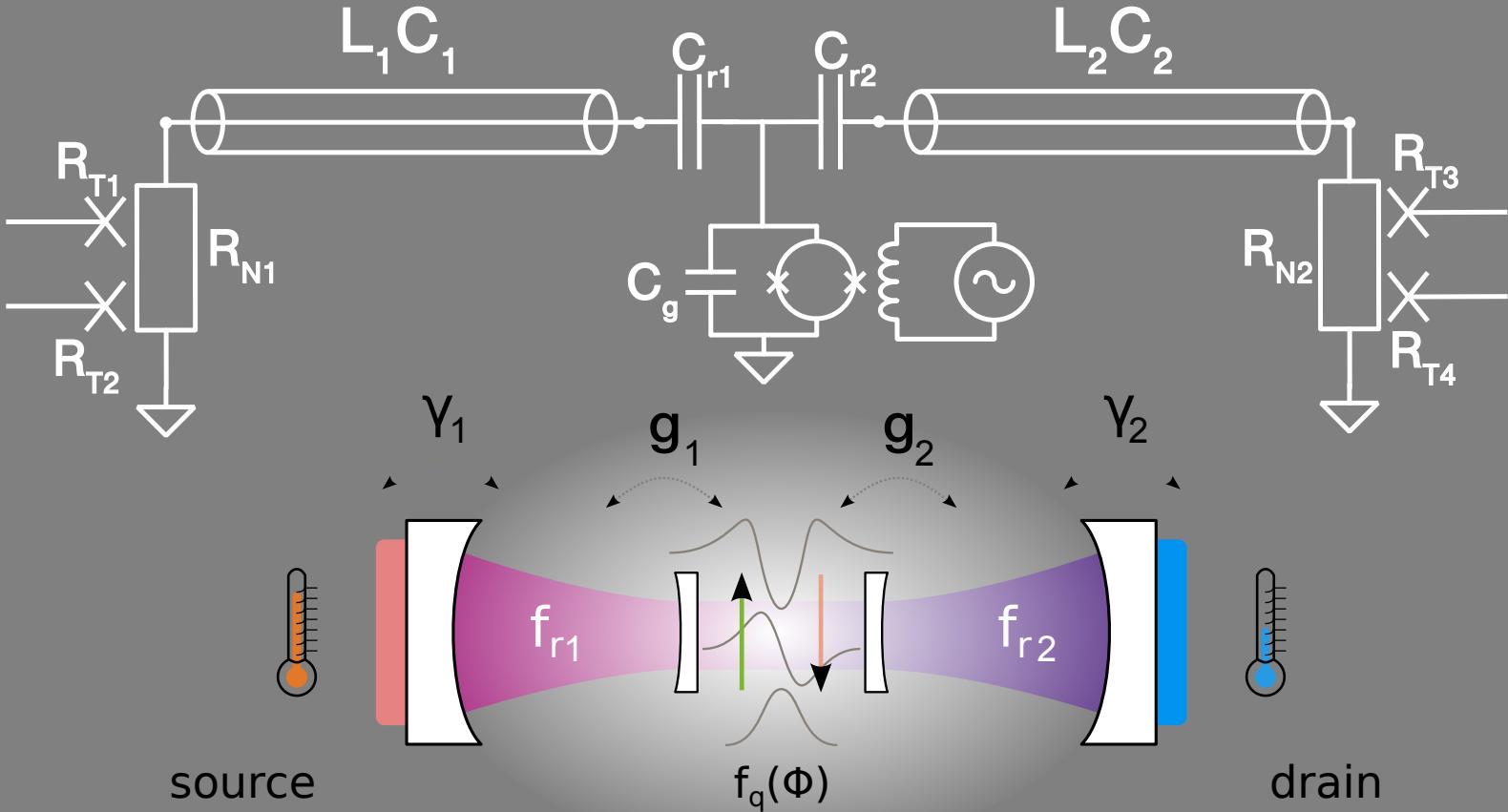


# $g/\gamma = 0.4$

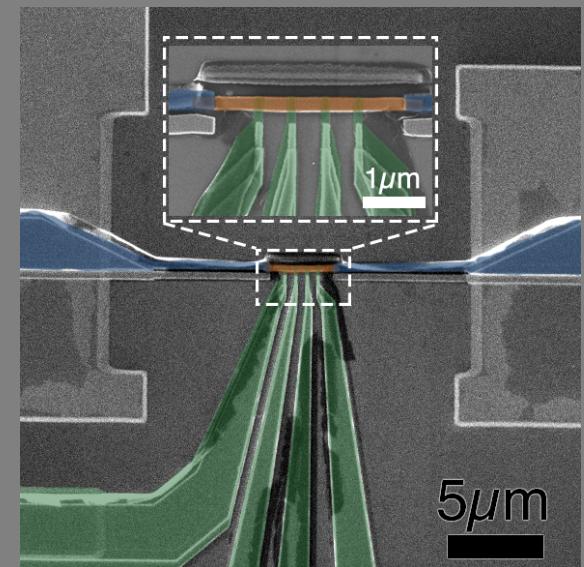
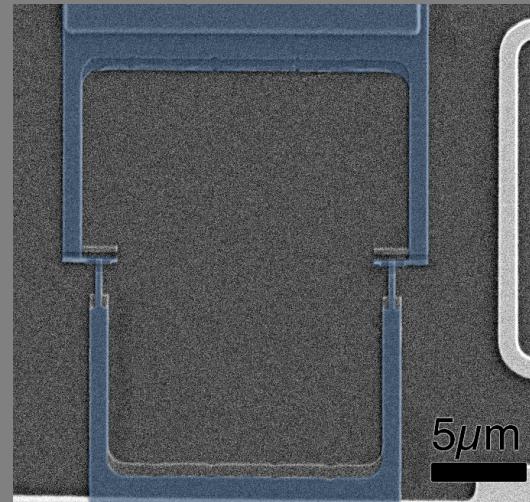
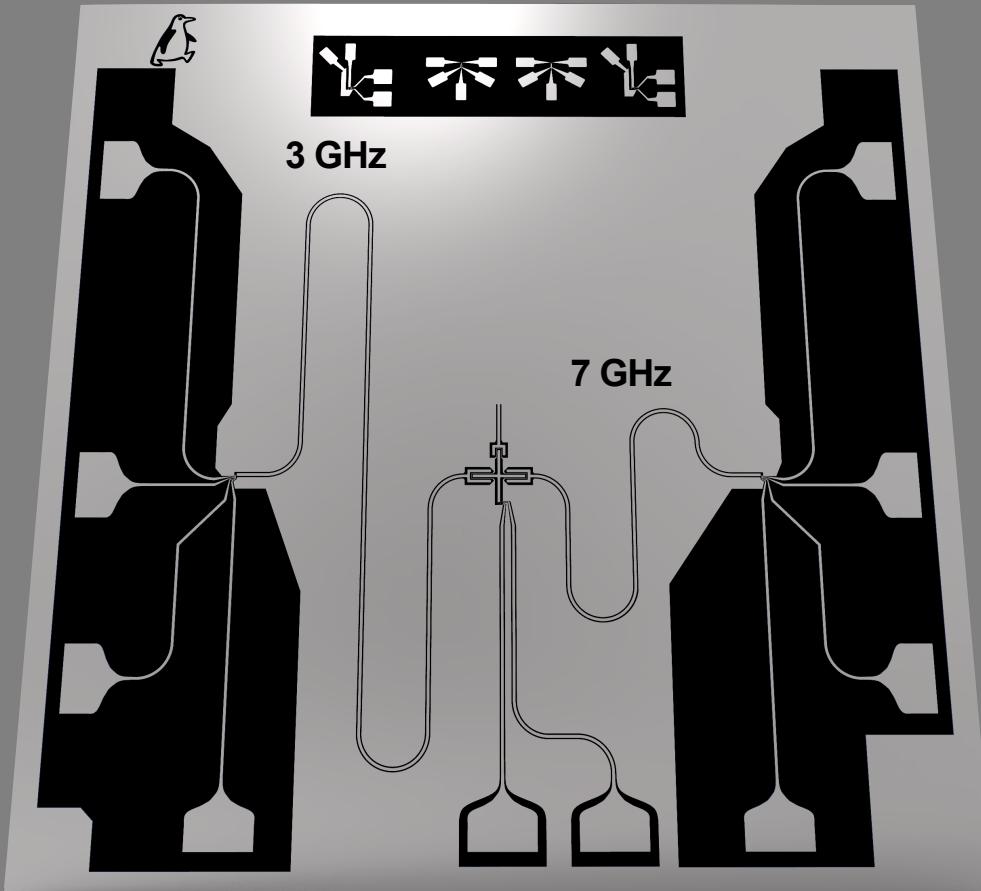


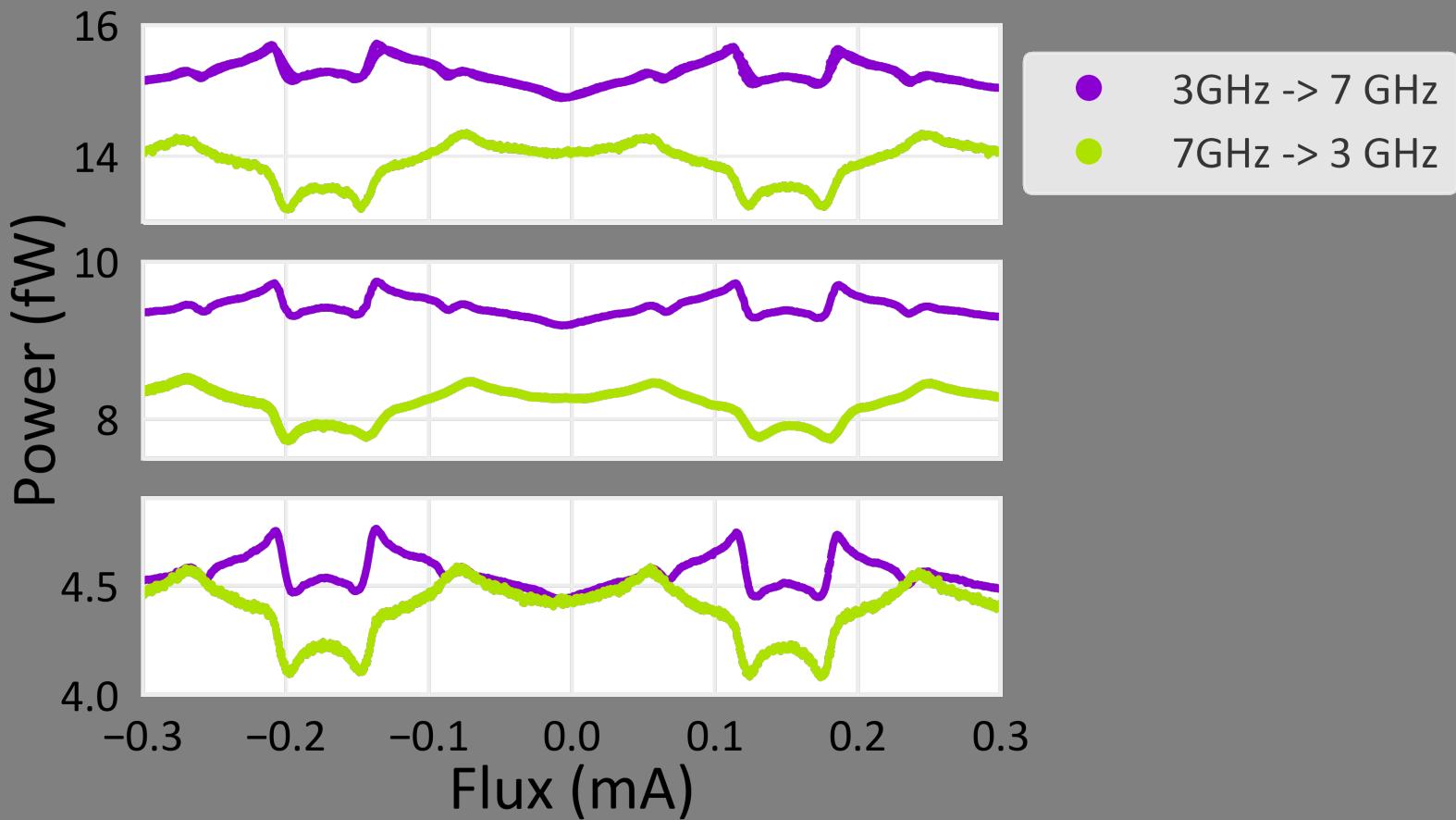


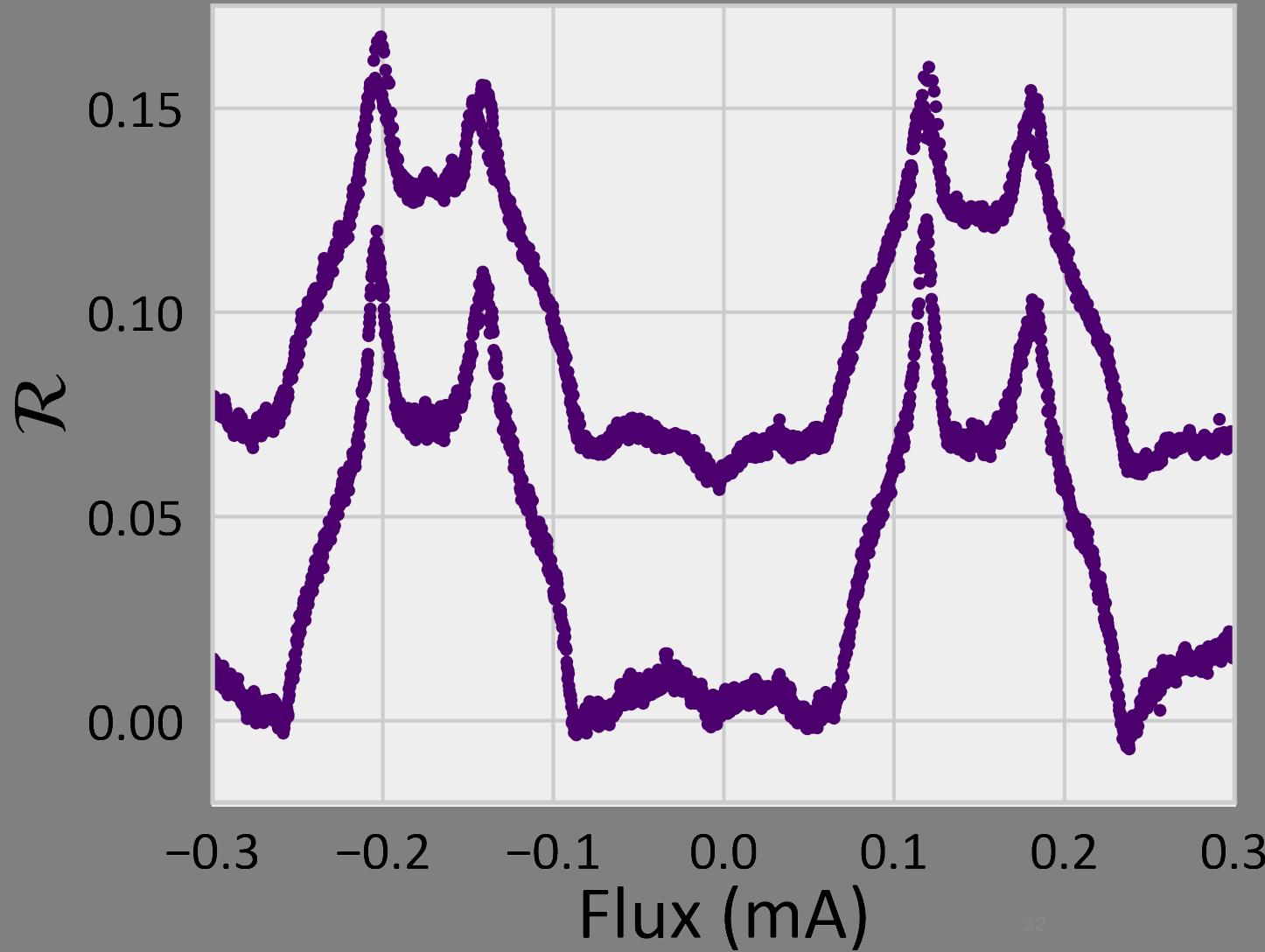
$$g/\gamma = 0.05$$
$$g/\gamma = 0.4$$



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)

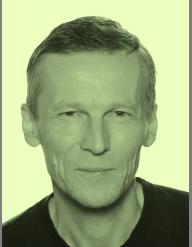
$g/\gamma \ll 1$   
Local

$g/\gamma \approx 1$   
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



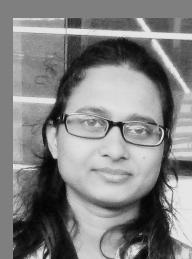
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Bayan Karimi



Brecht Donvil  
(University of Helsinki)



Shilpi Singh



Elsa Mannila



Marco Marín  
Suárez



Klaara Viisanen



Libin Wang



Rishabh Upadhyay

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