Imaging thermoelectric power at the nanoscale

B. Brun [1], S. Toussaint [1], F. Martins [1], S. Faniel [1], B. Hackens [1], V. Bayot [1], D. Mailly [4], U. Gennser [4], X. Wallart [5], L.Desplanque [5], S. Huant[2], M. Sanquer [3], H. Sellier [2]

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2017, March 21st

Outline

1. Transport in Quantum Point Contacts (QPCs)
2. Thermopower
   - The Seebeck coefficient
   - Thermopower of quantum point contacts
   - The Mott relation
3. Scanning gate thermoelectric microscopy
   - Scanning gate microscopy
   - SGTM on a QPC
   - SGTM on an InGaAs network
4. Conclusion

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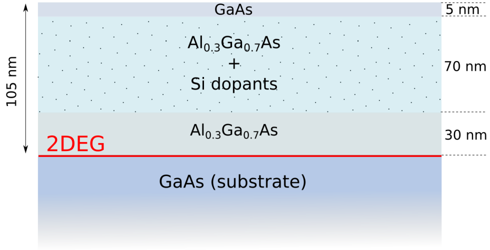
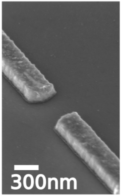


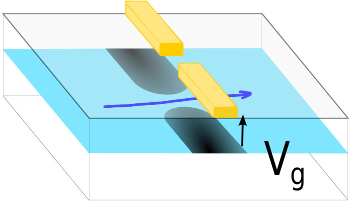
High mobility 2DEG are grown in LPN, Marcoussis

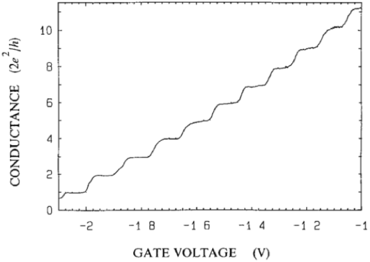
- Model two-dimensional systems
- Platform to study ballistic transport
- Interesting thermoelectric properties

Quantum Point Contacts (QPC)

Simplest quantum electronic device built in these structures:







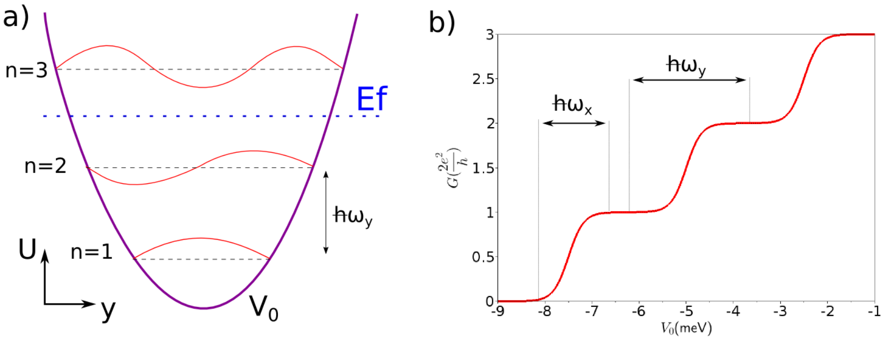
QPC conductance is quantized by steps of $2e^2/h$

First realized in 1988:
B. J. van Wees *et al.*, Phys. Rev. Lett (Delft)
D A Wharam *et al.*, Journal of Physics C (Cambridge)

The attached video can be found here
Feel free to use it on pedagogical purposes.

Visual: Benjamin Kuperberg

Quantum Point Contacts (QPC)



Each mode contributes for $2e^2/h$ to the conductance

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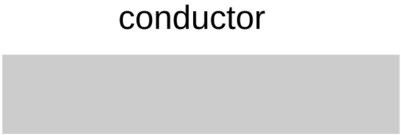
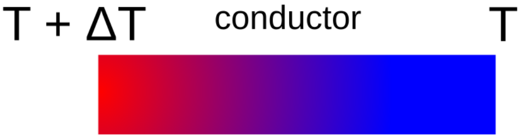
Discovery of the thermopower: 1821

Thomas Johann Seebeck

Discovery of the thermopower: 1821



Discovery of the thermopower: 1821



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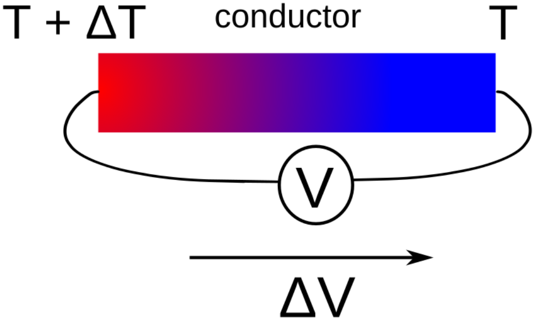


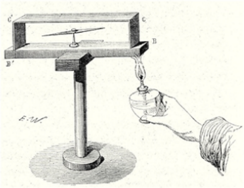
Discovery of the thermopower: 1821

Seebeck coefficient:

$$S = \frac{\Delta V}{\Delta T}$$

Order of magnitude for metals: $-100\mu V/K < S < +100\mu V/K$

Discovery of the thermopower: 1821



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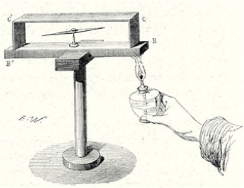
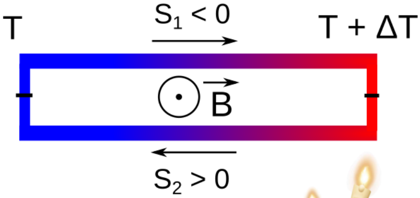
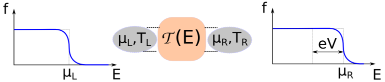


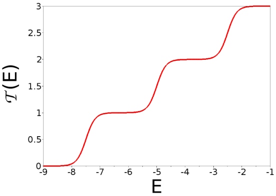


Thermopower of quantum point contacts

Differential conductance: $\boxed{G = dI/dV}$



$\mu_R = \mu_L + eV$



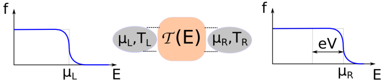
Thermopower of quantum point contacts

VOLUME 65, NUMBER 8 PHYSICAL REVIEW LETTERS 20 AUGUST 1990

Quantum Oscillations in the Transverse Voltage of a Channel in the Nonlinear Transport Regime

L. W. Molenkamp, H. van Houten, C. W. J. Beenakker, and R. Eppenga
Philips Research Laboratories, 5600 JA Eindhoven, The Netherlands

Differential conductance: $G = dI/dV$



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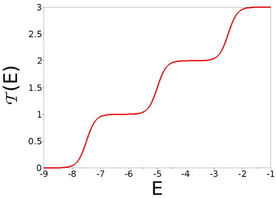
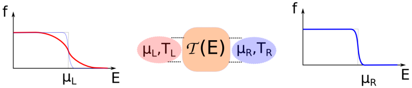
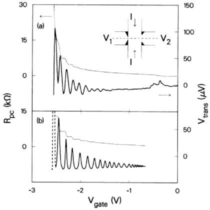


Thermopower: $S = dV/dT$

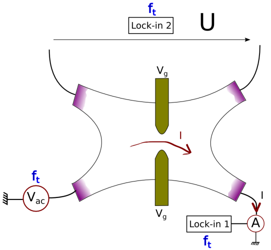


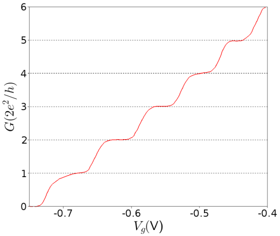
$T_R = T_L + \Delta T$



Measurement setup

Differential condcutance





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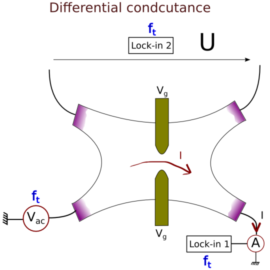
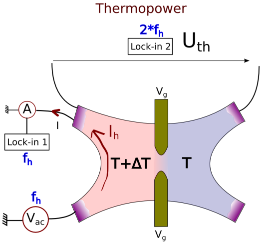
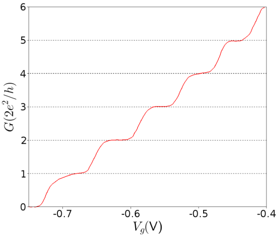
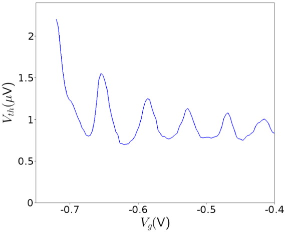


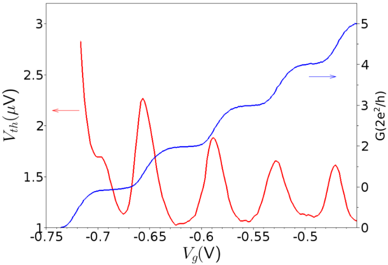
VS







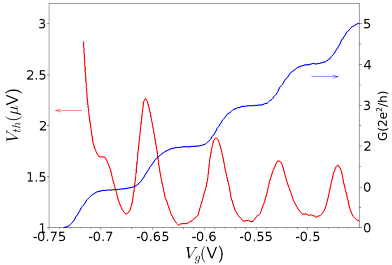
The Mott relation

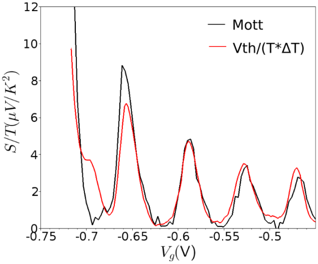


Mott relation:

$$S_{Mott} = -\frac{\pi k_B^2 T}{3e} \frac{1}{G} \frac{\partial G}{\partial \mu} \propto \frac{1}{G} \frac{\partial G}{\partial V_g}$$

The Mott relation





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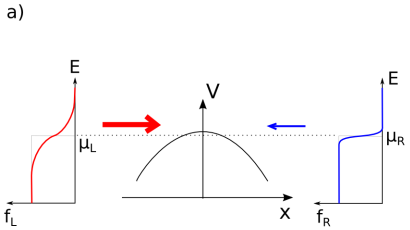

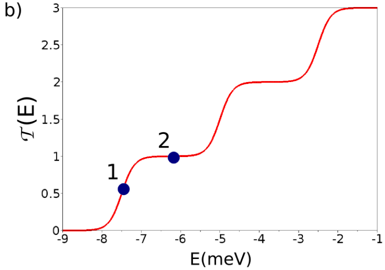

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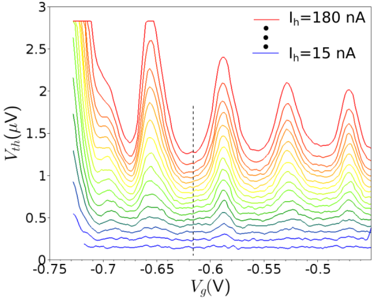

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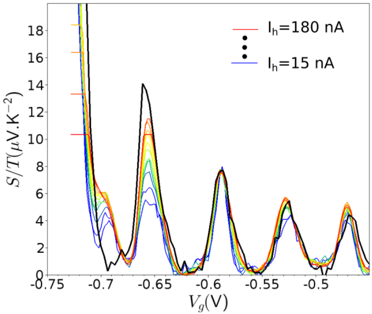

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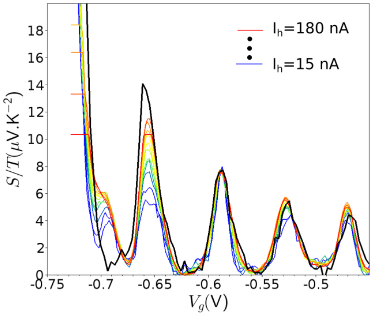

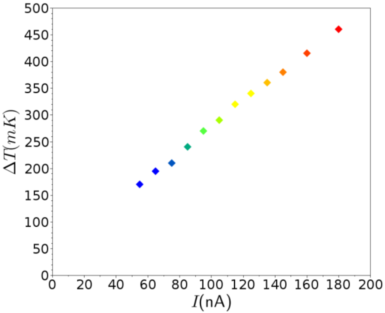

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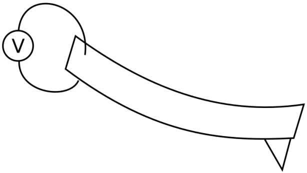
Scanning gate microscopy: principle

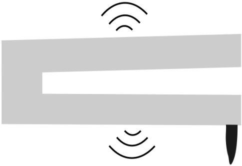
Westervelt group, Harvard, 1996

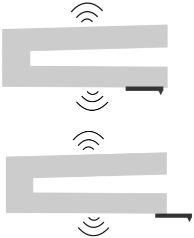
Self-sensing tips

Laser detection of the cantilever is forbidden, therefore:

- Use of piezoelectric cantilever, home-coated
- Glue a tungstene wire (eventually FIB-etched) on a tuning fork
- Glue a commercial tip on a tuning fork







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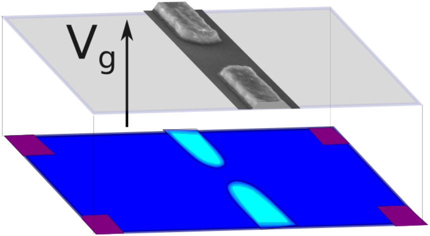

M. A. Eriksson, Appl. Phys. Lett. (1996)
(Westervelt group, Harvard)

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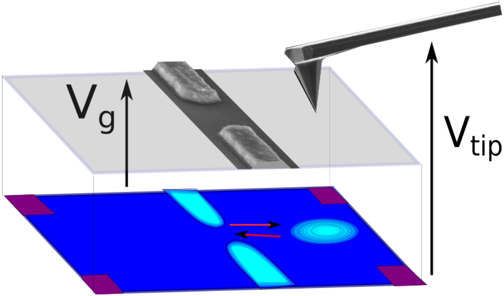

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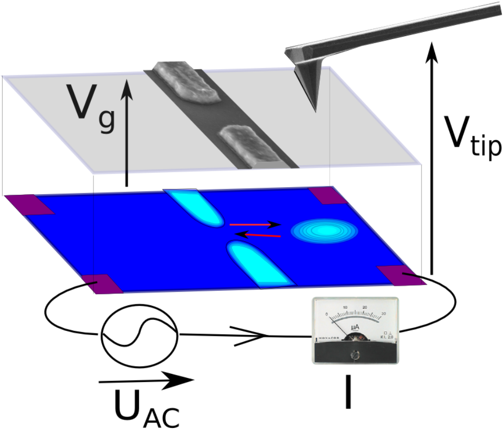

See also: M. A. Topinka et al., Nature **410** (2001).
R. Crook et al., Science, **312** (2006).
N. Paradiso et al., Phys. Rev. Lett., **108** (2012).
A. A. Kozikov et al., New. J. Phys. **15** (2013)

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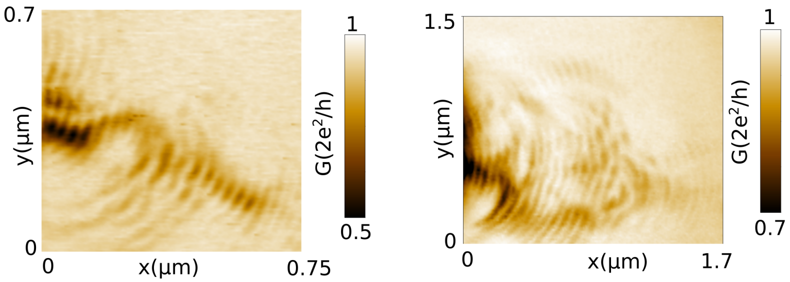
Visual: Benjamin Kuperberg

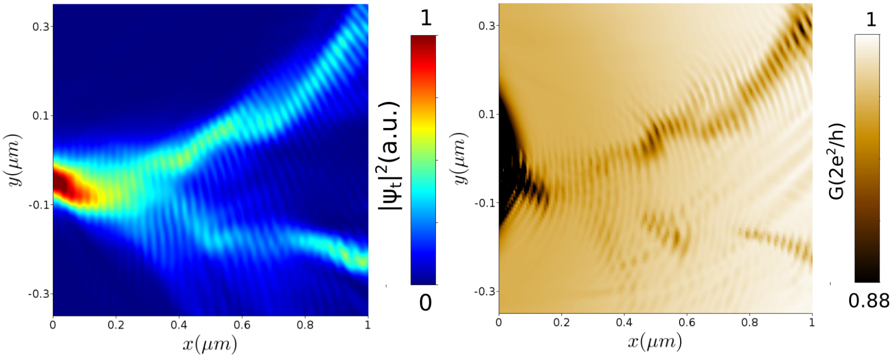
Imaging quantum transport

Experiments:



Imaging quantum transport

Calculation:



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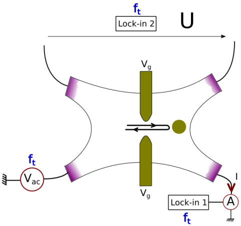

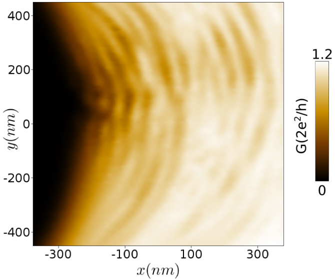

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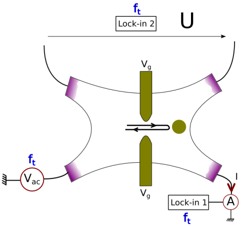

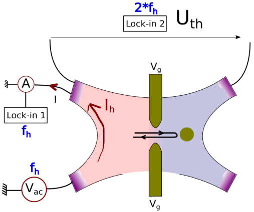

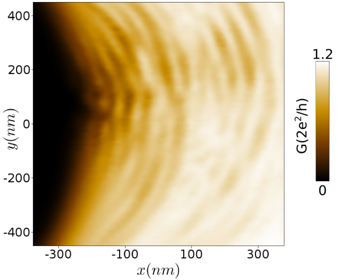

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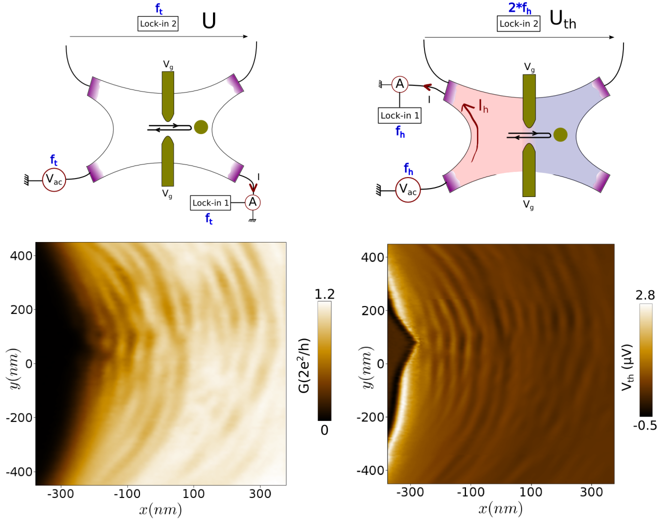

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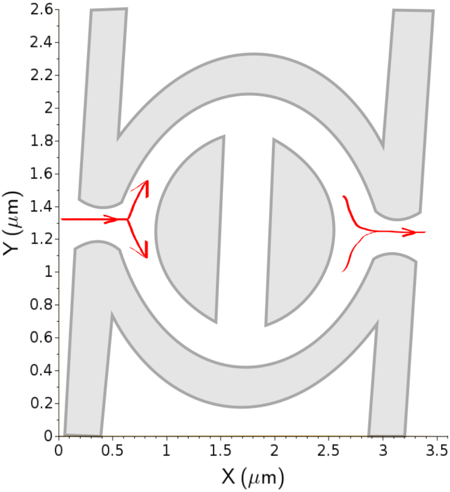

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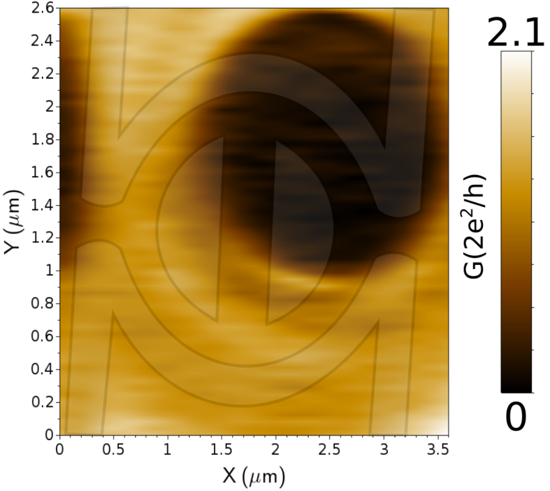

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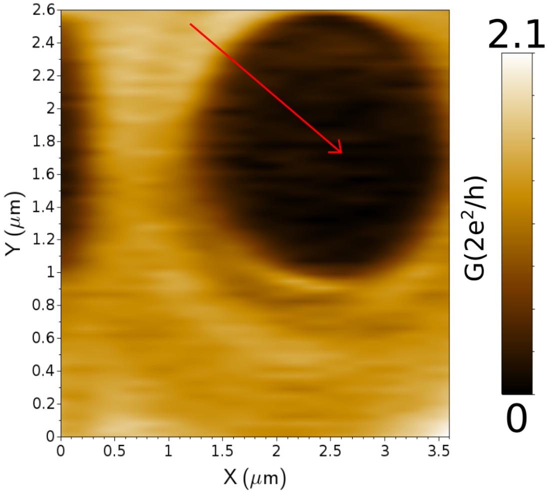

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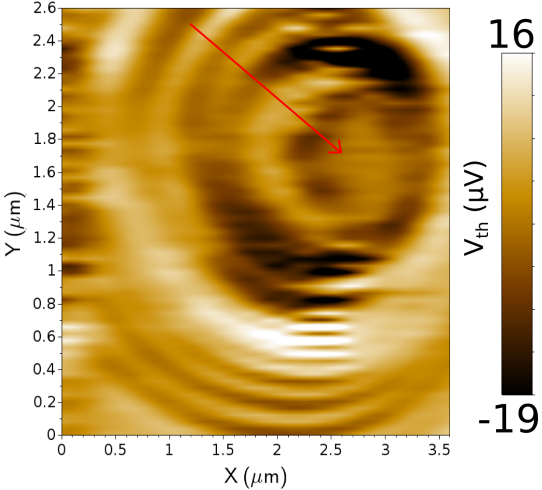

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Conclusion

- We explore thermopower of two-dimensional electron gases
- A local approach has been developed, inspired by scanning gate microscopy
- In the future, we will focus on other signals (thermal conductivity and Peltier coefficient) and on different materials (graphene)

Conclusion

Thank you,
and let's go to the Spa!