A review of Jukka Pekola's scientific career

Hervé Courtois
Institut Néel, Univ. Grenoble Alpes

Jukka's CV

1984 D.Sc. in Technology (Physics), **Helsinki** UT

1985 – 86 Postdoc researcher, Physics Department, UC **Berkeley**, California
1987 – 92 Group leader, Low Temperature Laboratory, HUT

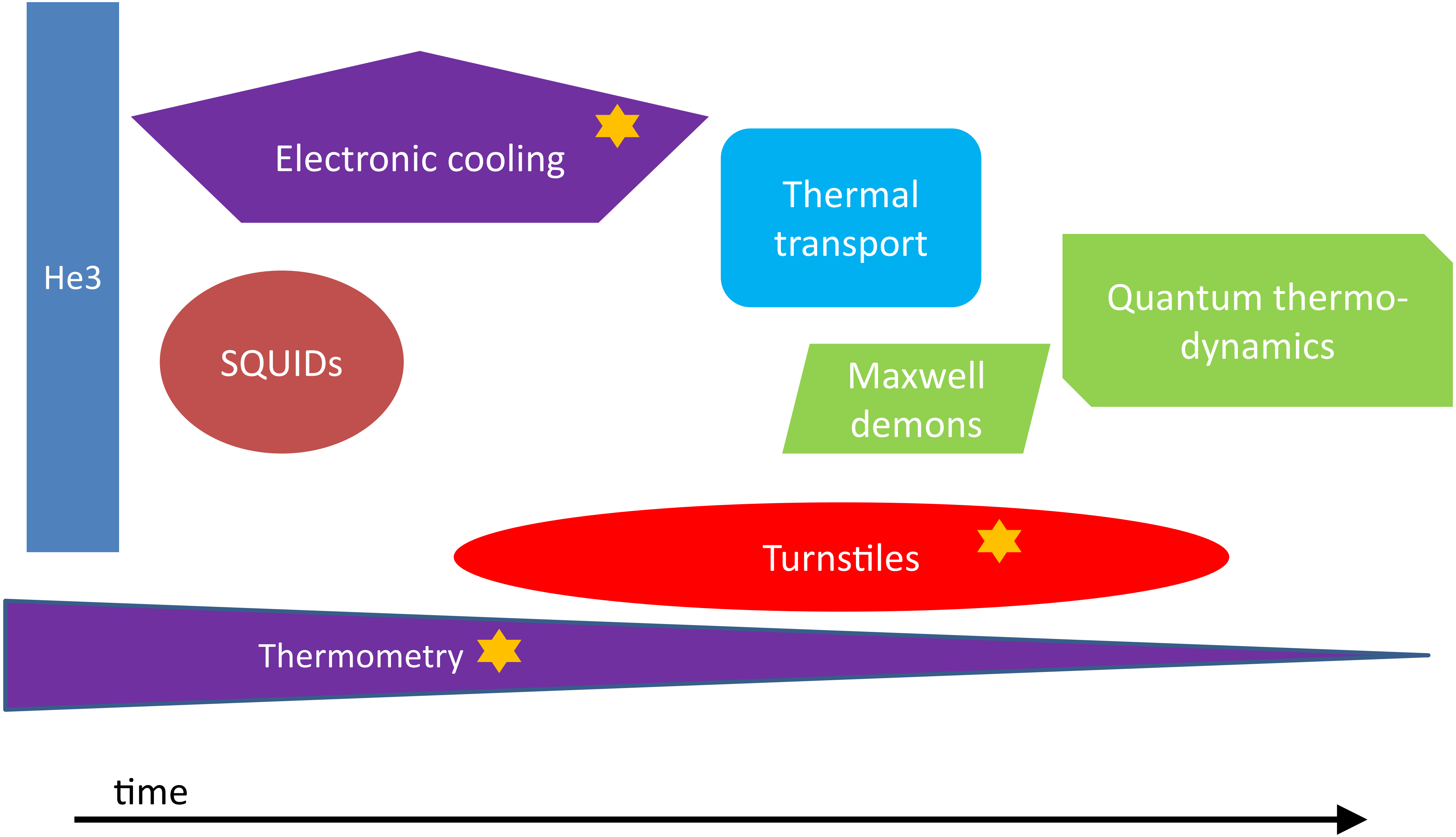
1992 – 95 Senior scientist, University of **Jyväskyla,** Finland
1995 – 97 Associate Professor in Applied Physics, JyU
1997 – 02 Professor in Physics, University of Jyväskyla
2000 – 05 & 2014 – Academy Professor, Academy of Finland

2001 – 02 Visiting professor, CNRS and U. Joseph Fourier, **Grenoble**

2002 – 12 Professor, LTL, **Helsinki**, HUT, Aalto U. after 2010
2012 – Full professor of Quantum Nanophysics, Aalto

2016 Theodor Homén Prize, Finnish Academy of Science and Letters
2001 Member of the Finnish Academy of Sciences and Letters (by election)
2001 Member of the Finnish Academy of Technical Sciences (by election)
2012 – 17 Director of the CoE on « Low temp. qu. phenomena & devices »
2018 – 25 Director of the CoE on « Quantum Technology Finland »
2017 ERC laureate

Topics

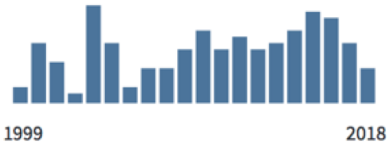


He3
Electronic cooling
Thermal transport
SQUIDs
Quantum thermo-dynamics
Maxwell demons
Turnstiles
Thermometry
time

Bibliography

Total Publications

335 Analyze



h-index

42

Average citations per item

20,17

Sum of Times Cited

6 757

Without self citations

5 484

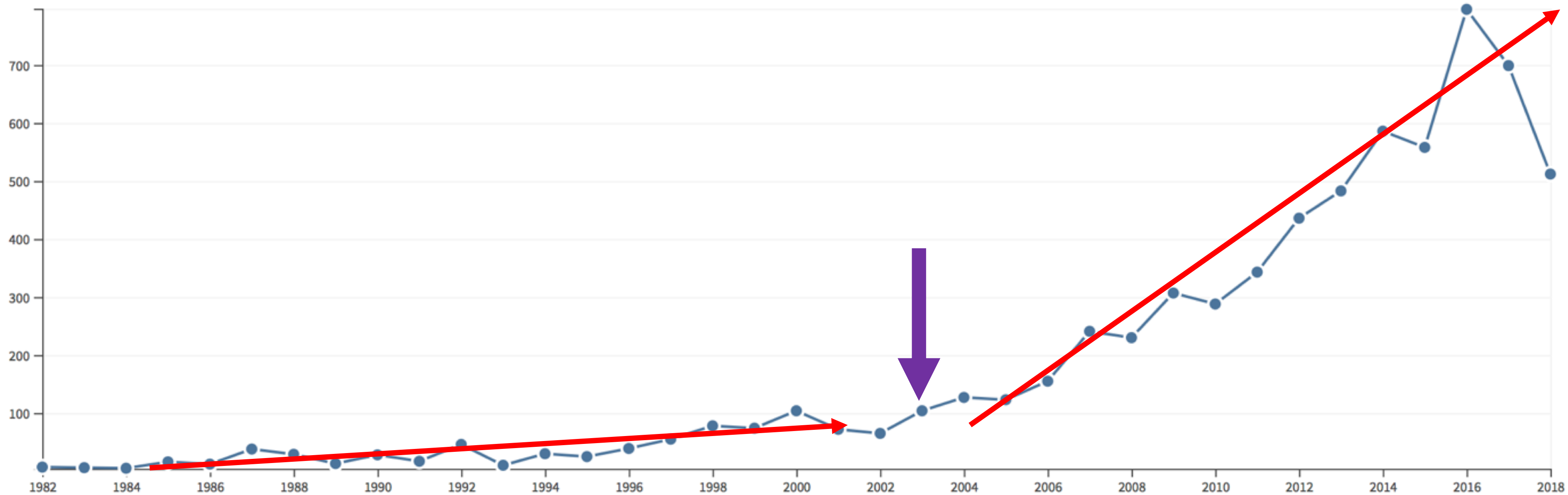
Citing articles

3 382 Analyze

Without self citations

3 107 Analyze

Sum of Times Cited per Year



Jukka in Grenoble

Invited professor by Bernard Pannetier at UJF and CNRS in 2001-02:
- with Henri Godfrin (thermometry with SETs)
- with Olivier Buisson & Frank Hekking (SQUID qubits)

Chair of Excellence 2015-18 of Nanoscience fundation with Frank Hekking, Hervé Courtois and Clemens Winkelmann.

Shared EU projects:
NanoSciERA Nanofridge,
Marie Curie ITN Q-NET,
QuESTech, FET INFERNOS.

ESONN lecturer

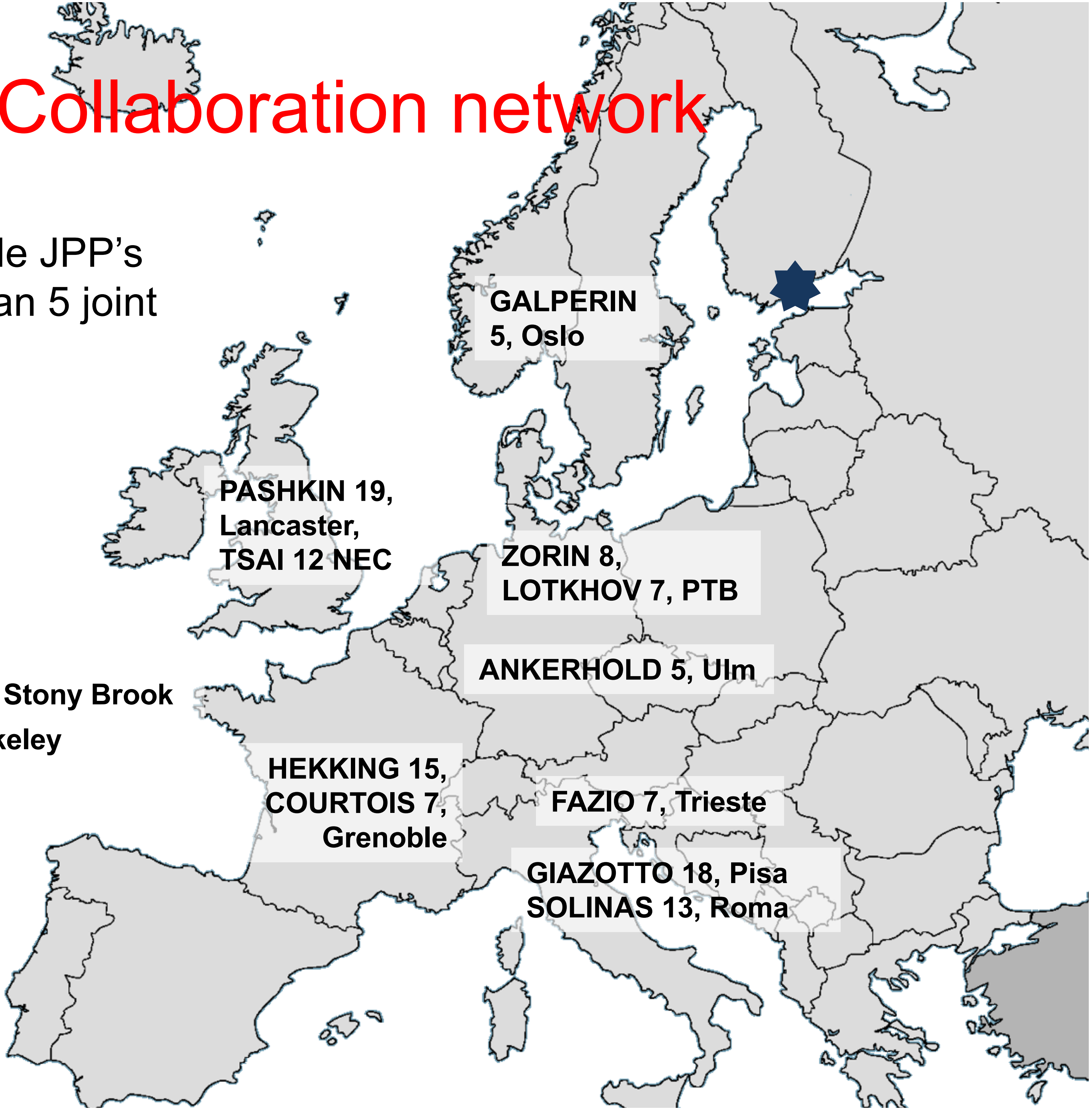
October 2017, near Grenoble

Collaboration network

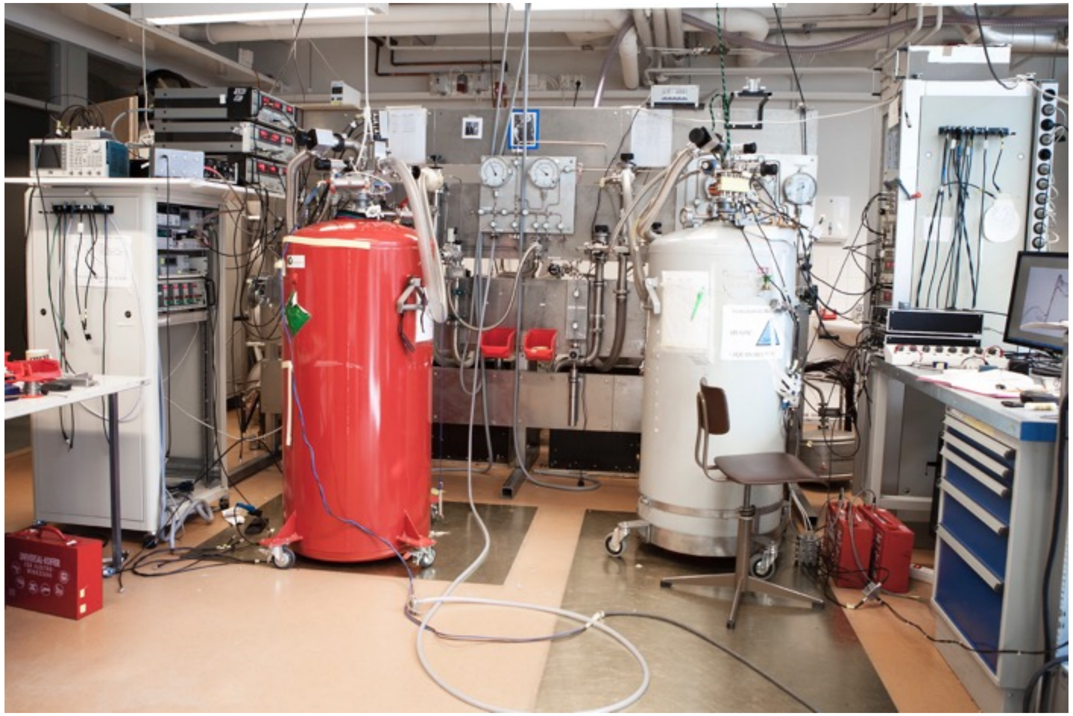
Collaborators outside JPP's group, with more than 5 joint papers:

AVERIN 25, KOROTKOV 5, Stony Brook

PACKARD 8, DAVIS 5, Berkeley



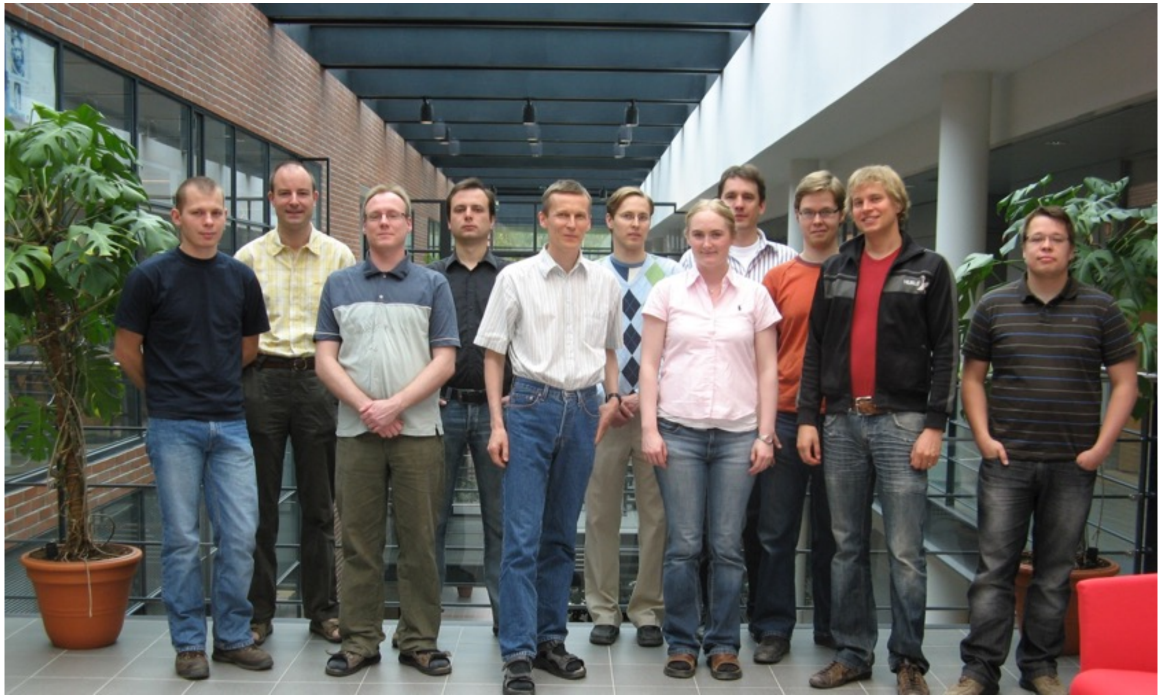
MicroNova



Versatile cryogenic set-up

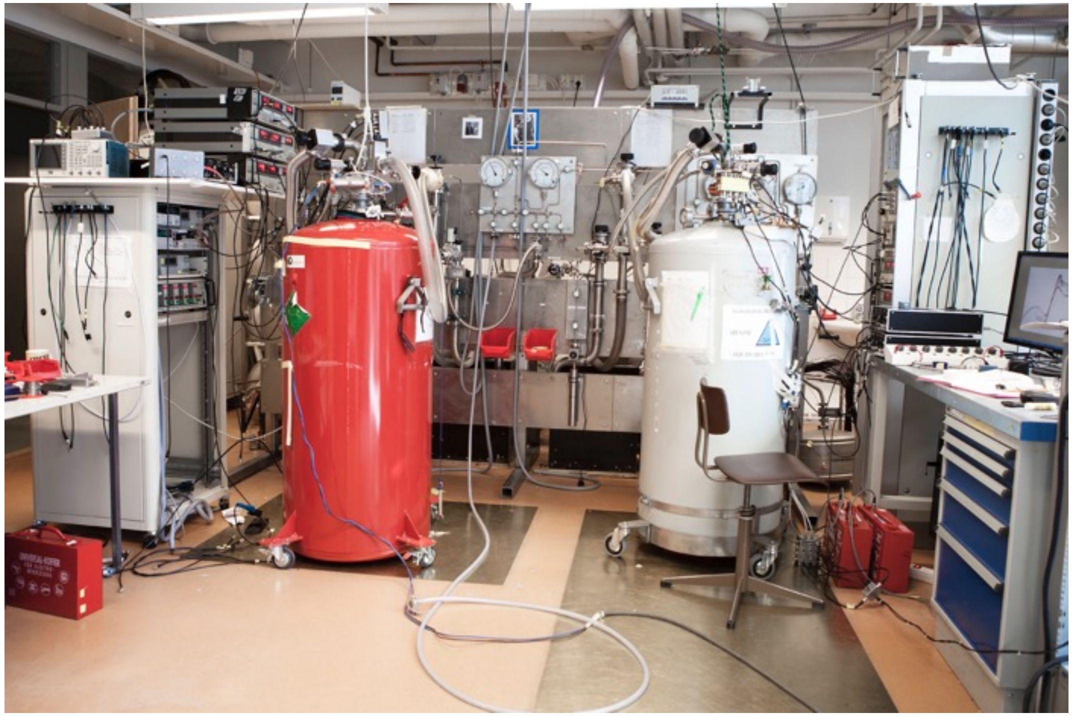
State-of-the-art clean room

Nice place



J. P. Pekola and J. P. Kauppinen, Cryogenics 34, 843 (1994).

MicroNova



Versatile cryogenic set-up

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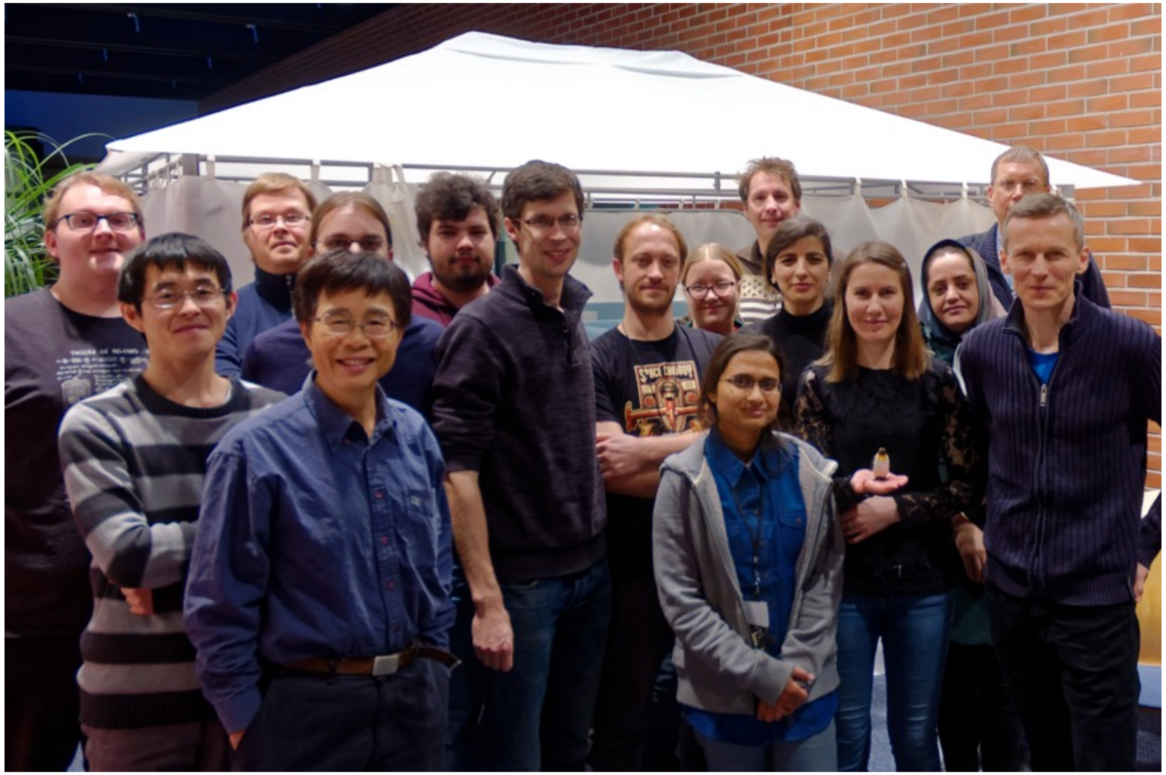


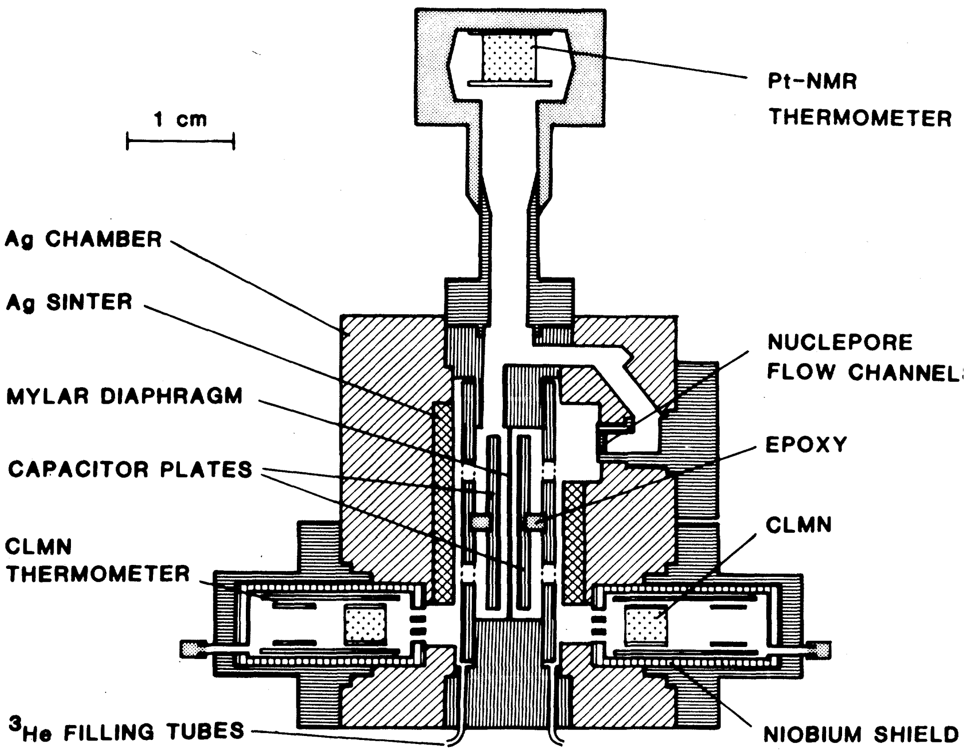
J. P. Pekola and J. P. Kauppinen,
Cryogenics 34, 843 (1994).

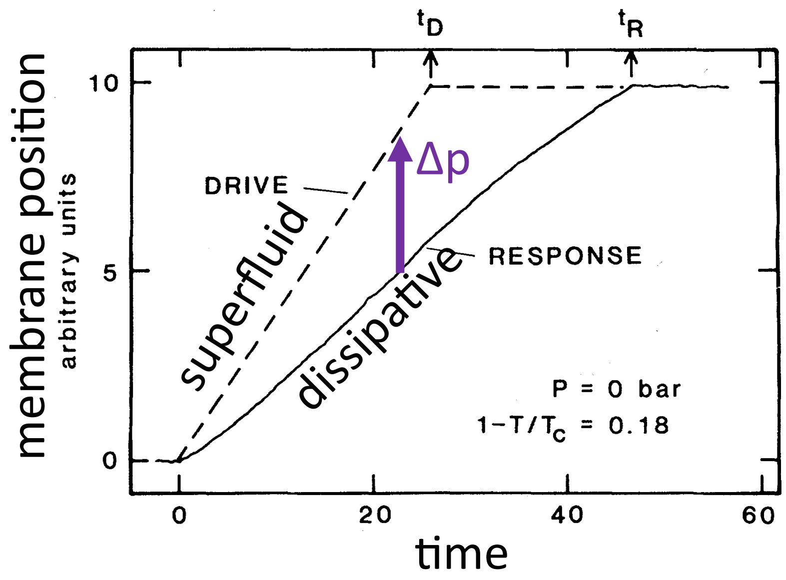
“Critical flow and persistent current experiments in superfluid ^3He”

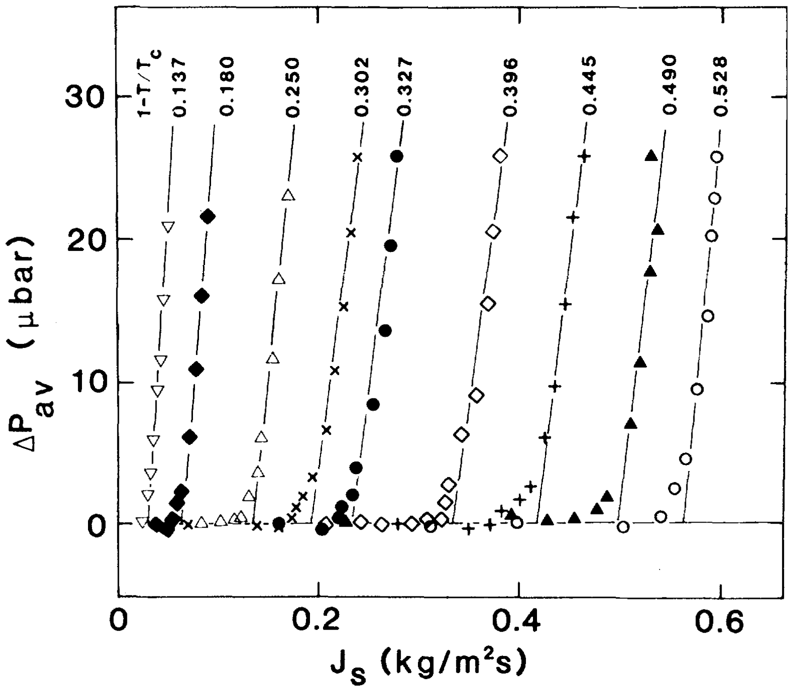
The critical velocity of superfluid ^{3}He

Flow of ^{3}He through 0.8 µm-diameter holes

Pressure difference measurement with a capacitive sensor







Temperature dependence of the critical flow

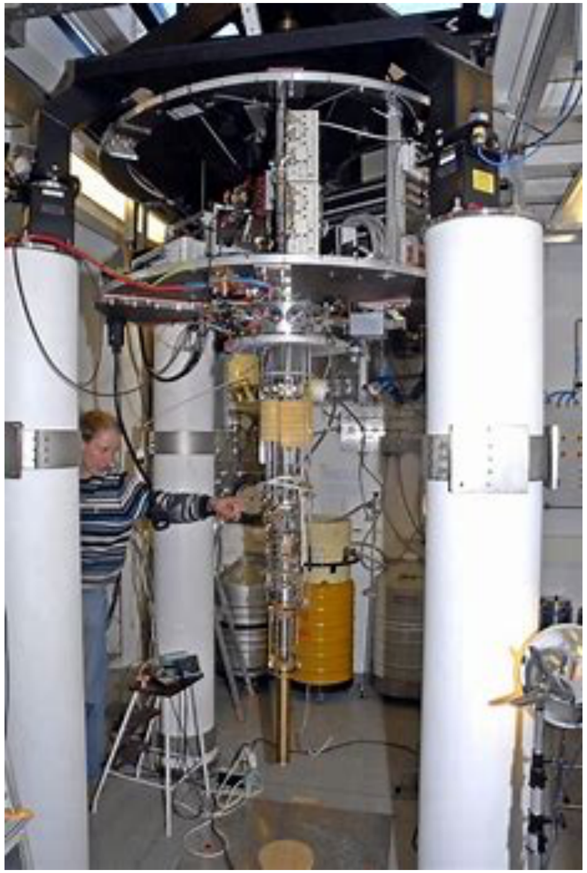
M. T. Manninen, J. P. Pekola, PRL 48, 812 (1982).

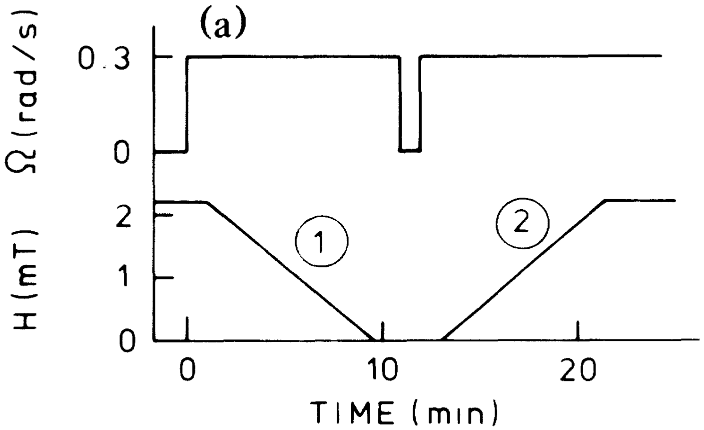
A topological transition in the ^{3}He-A vortices

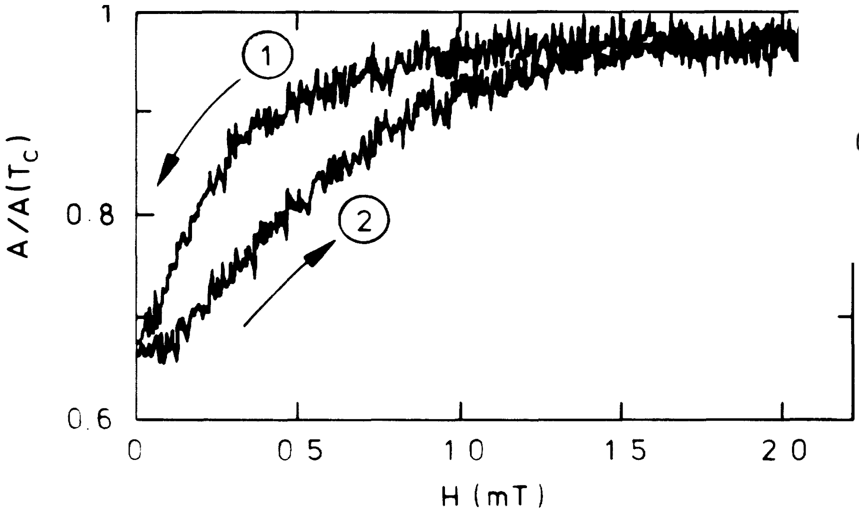
Pulsed ultrasound transmission 26-44 MHz experiments in a rotating cryostat

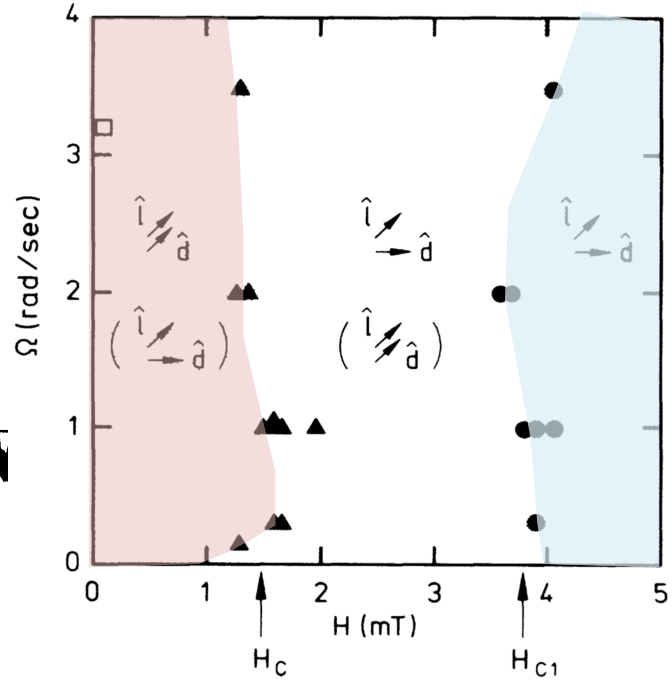
Phase diagram of vortex textures in ^{3}He-A

First-order transition between phases of vortices of different vorticity values









J. P. Pekola, K. Torizuka, A. J. Manninen, J. M. Kyynäräinen, G. Volovik, PRL 65, 3293 (1990)

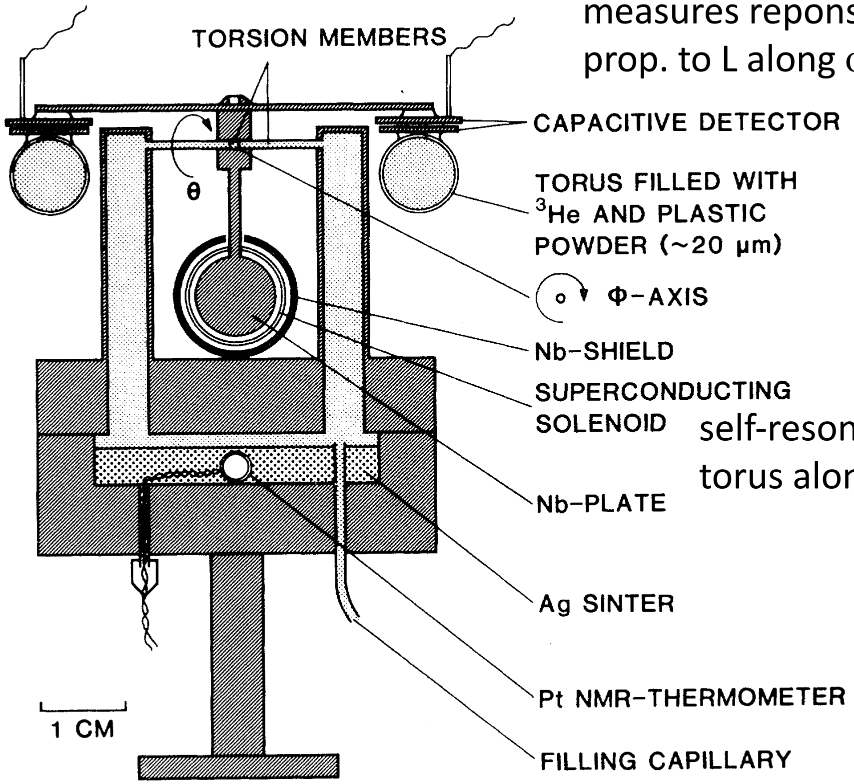
Persistent currents in superfluid ^{3}He-B & A

Torus filled with ^{3}He and powder: angular momentum L proportional to velocity

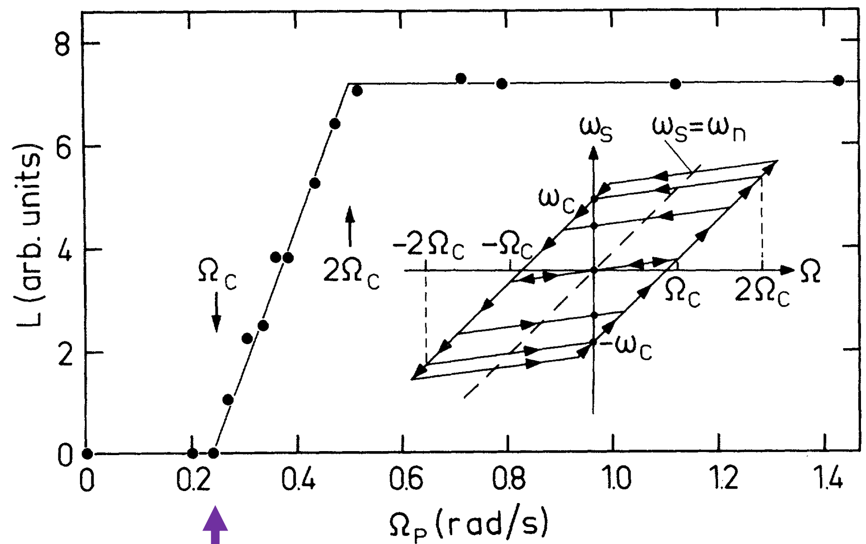
Gyroscope at rest after rotation: superfluid effects 100x smaller than Coriolis

Persistent flow in B phase with damping time 450 h, none in A phase

measures reponse prop. to L along ϕ



self-resonantly drives the torus along θ



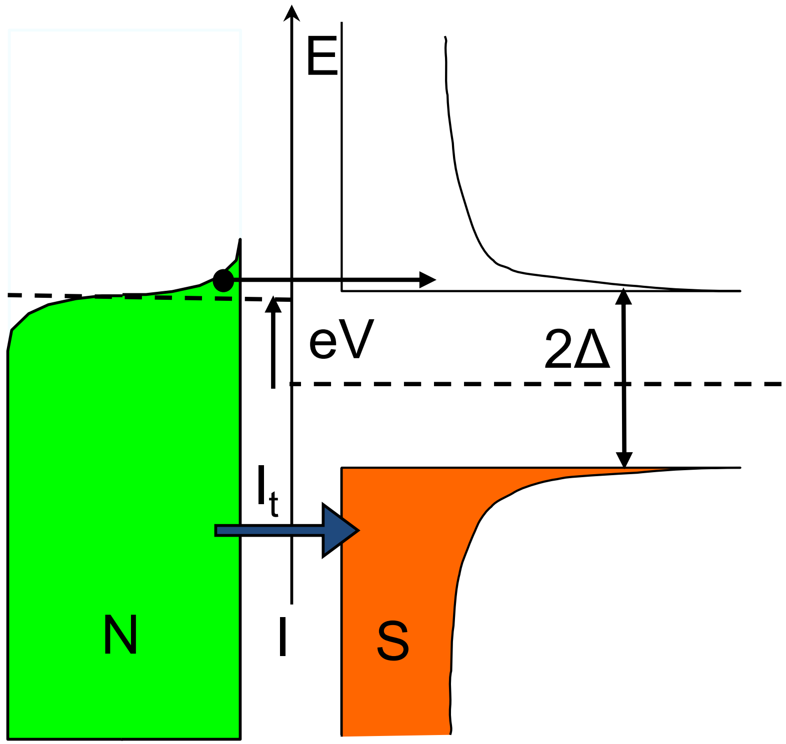
Transition from reversible to irreversible

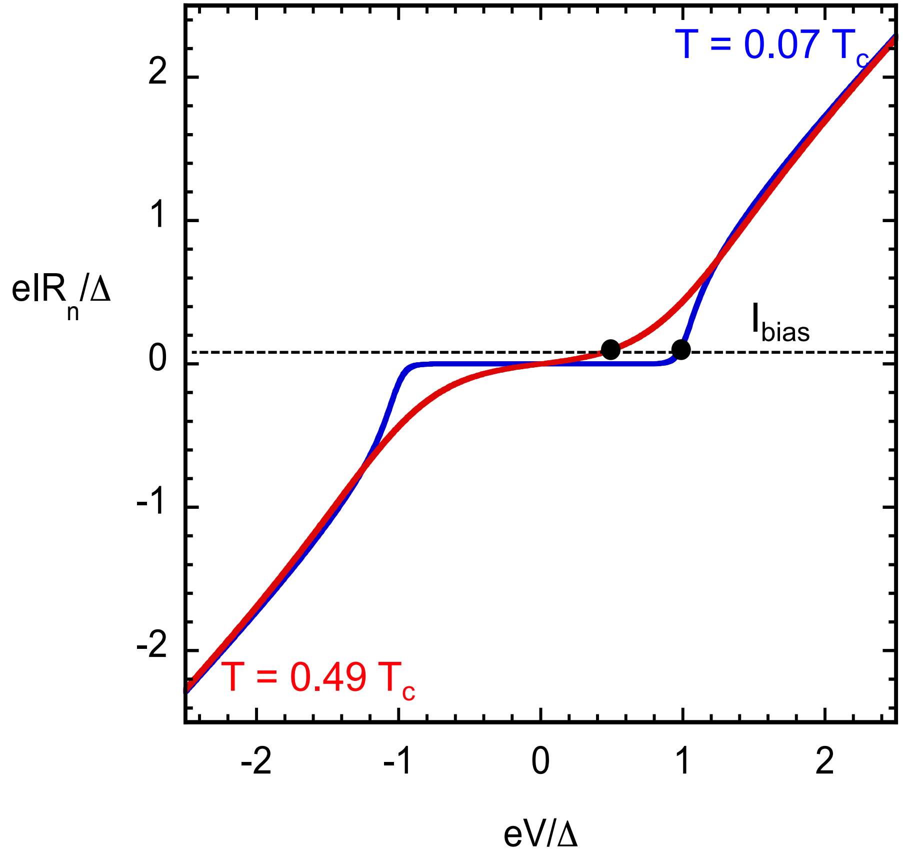
J. Pekola, J. T. Simola, K. K. Nummila, O. V. Lounasmaa, R. E. Packard, PRL 53, 70 (1984)

“SINIS always works“

J. P. Pekola, private communication (2008).

Charge current in a N-I-S tunnel junction



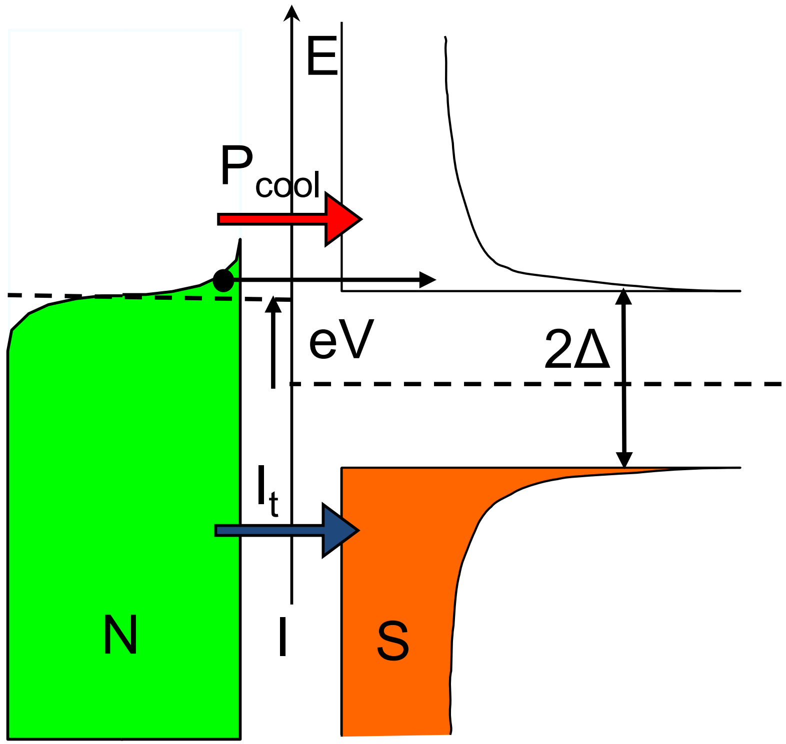


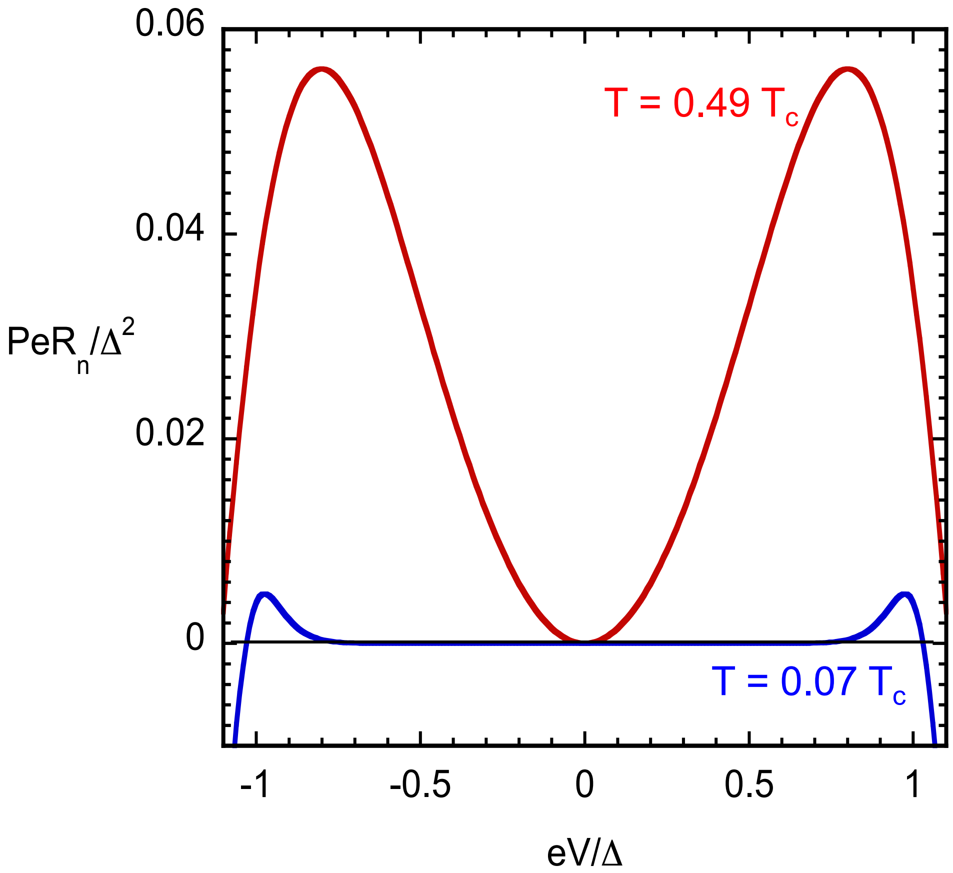
The energy gap induces an energy-selective tunnel charge current:

$$I_T = \frac{1}{eR_n}\int_{-\infty}^{+\infty} n_S(E)\left[f_S(E-eV) - f_N(E)\right]dE$$

At a fixed bias current: sensitive electron thermometer. Low current needed.

Heat current in a N-I-S tunnel junction





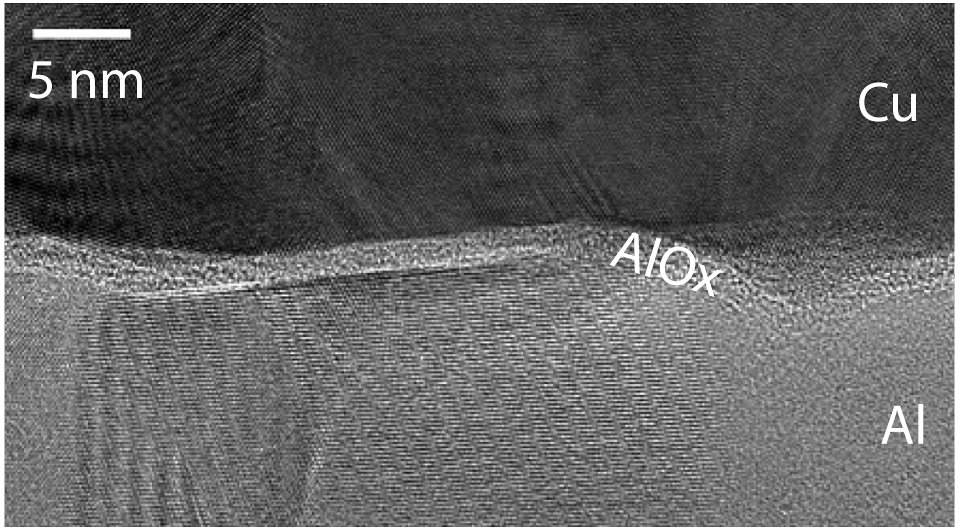
Heat current (symmetric in bias):

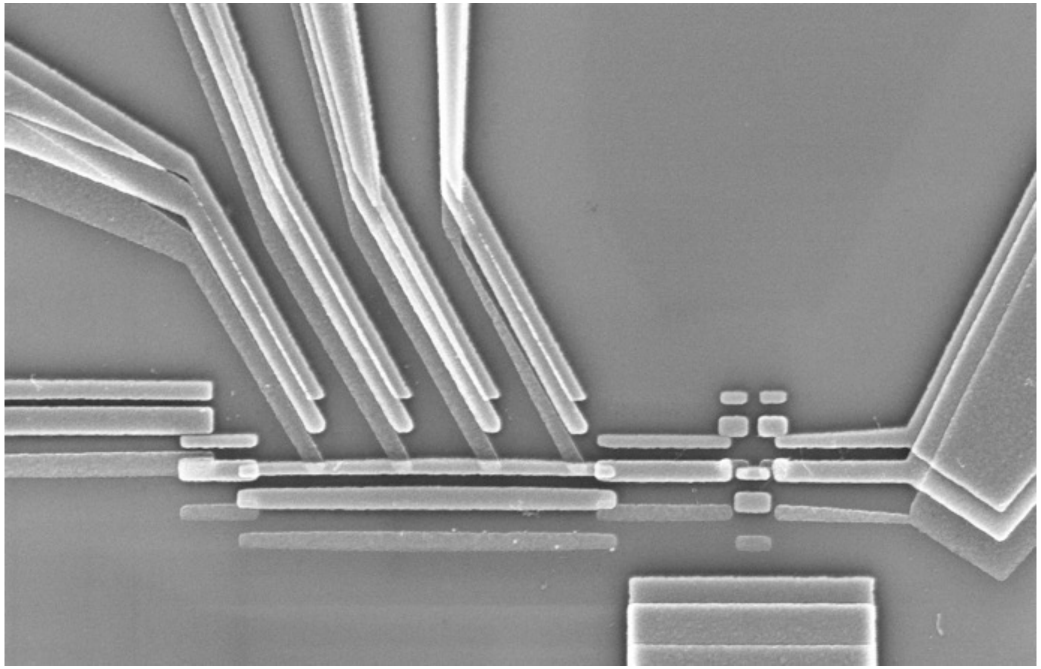
$$\dot{Q}_{cool}(V) = \frac{1}{e^2 R_n} \int_{-\infty}^{+\infty} (E - eV) n_S(E) \left[f_N(E - eV) - f_S(E) \right] dE$$

For eV < Δ: electronic cooling in N, for eV >> Δ: Joule power IV.

How does it work ?

The miracle of Al oxide + advanced lift-off lithography





T. Aref, A. Averin, S. van Dijken, A. Ferring, M. Koberidze, V. F. Maisi, H. Q. Nguyen, R. M. Nieminen, J. P. Pekola, L. D. Yao, JAP 116, 073702 (2014)

Electronic cooling

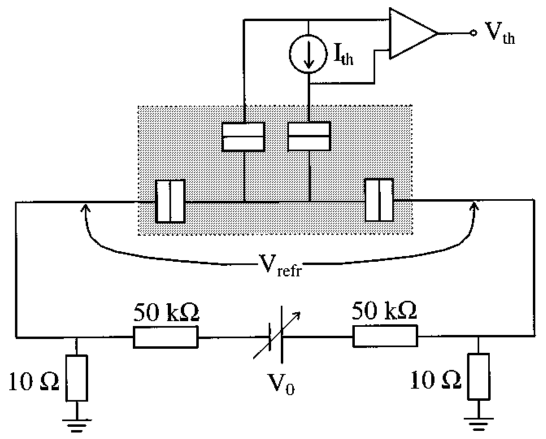
Electronic cooling

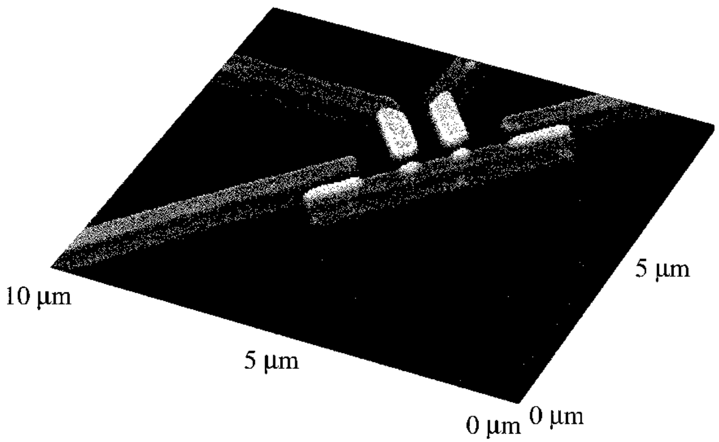
First demonstration of electronic cooling in a NIS junction in a single junction:

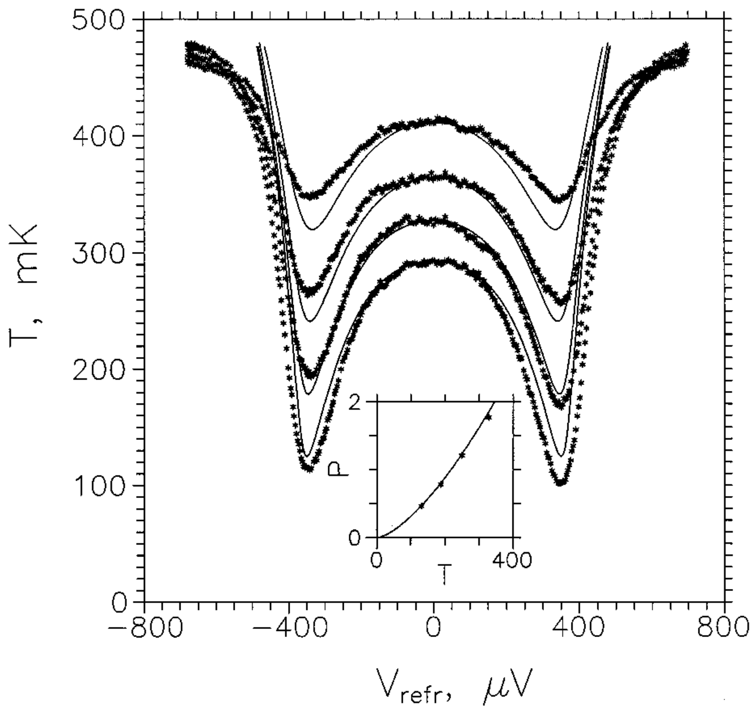
M. Nahum, T. M. Eiles & J. M. Martinis, APL 65, 3123 (1994).

What is stronger than a turk ?

SINIS: pW-scale power.

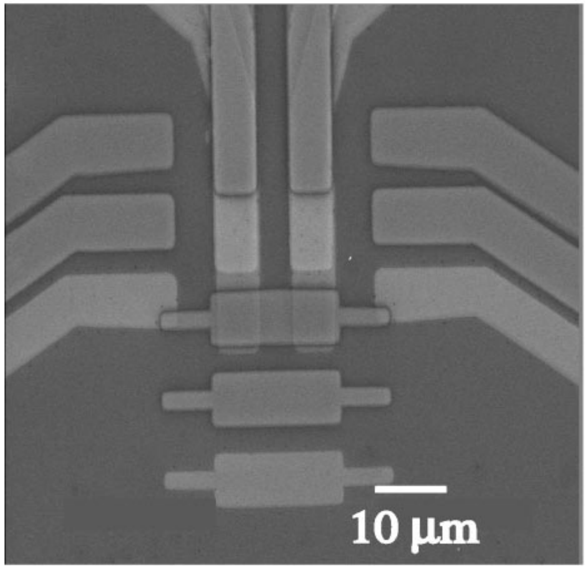


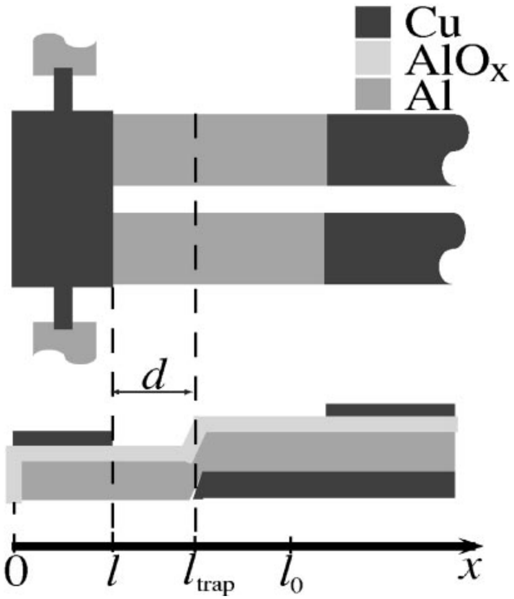


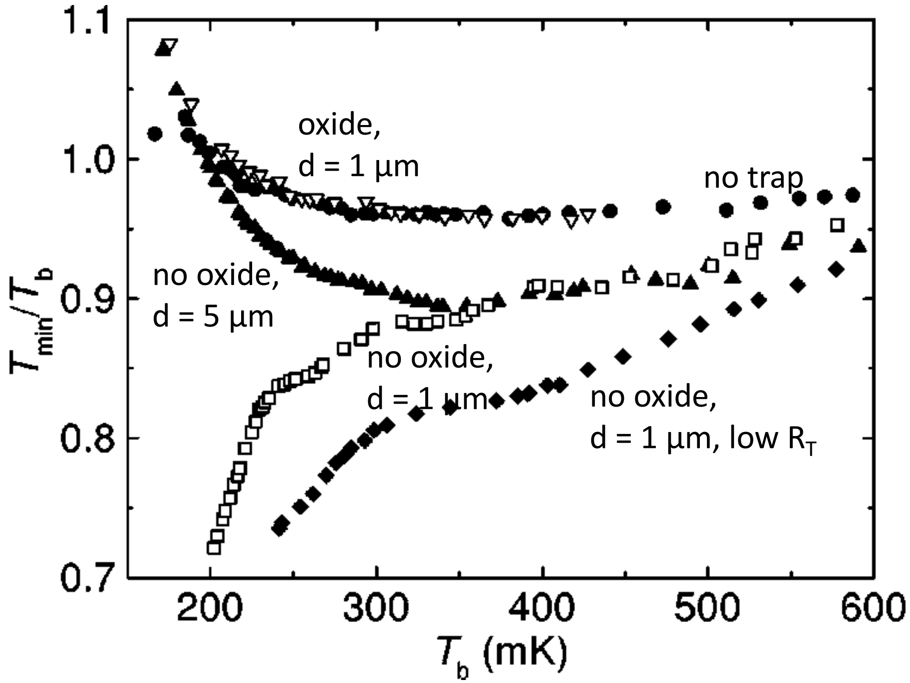


M. M. Leivo, J. P. Pekola, D. V. Averin, APL 68, 1996 (1996).

Trapping of quasi-particles





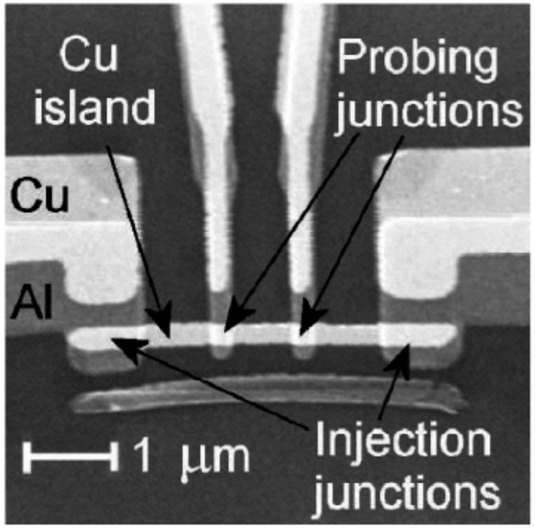


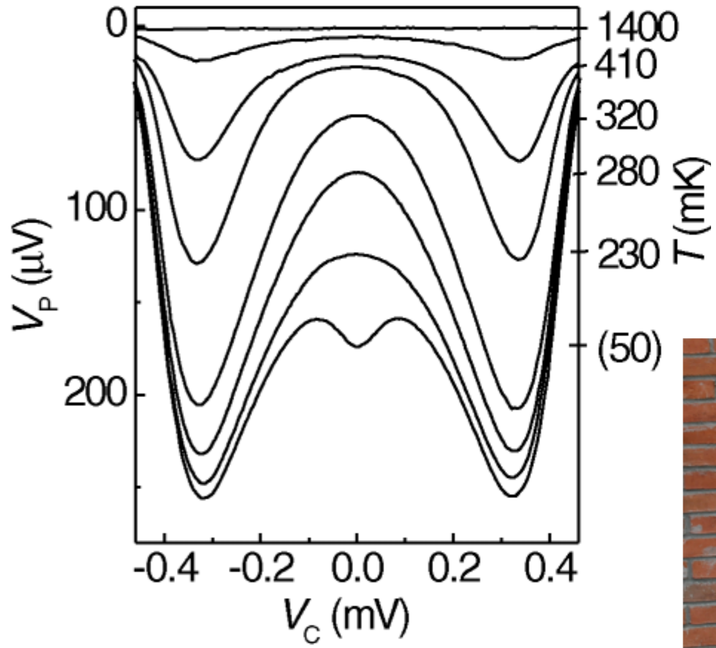
Hot quasi-particles accumulate in the S

Back-tunneling limits cooling efficiency

J. P. Pekola, D. V. Anghel, T. I. Suppula, J. K. Suoknuuti, A. J. Manninen, and M. Manninen, APL 76, 2782 (2000).

Limitations of electronic cooling





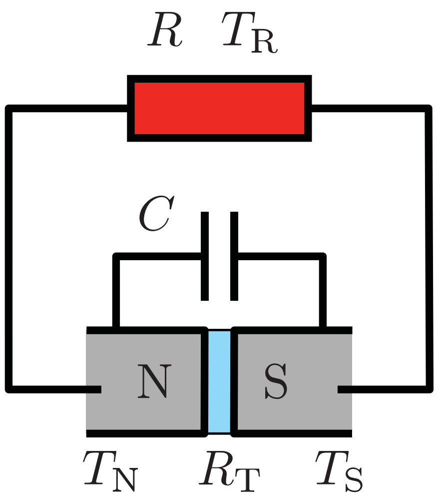
Out of equilibrium distribution in N

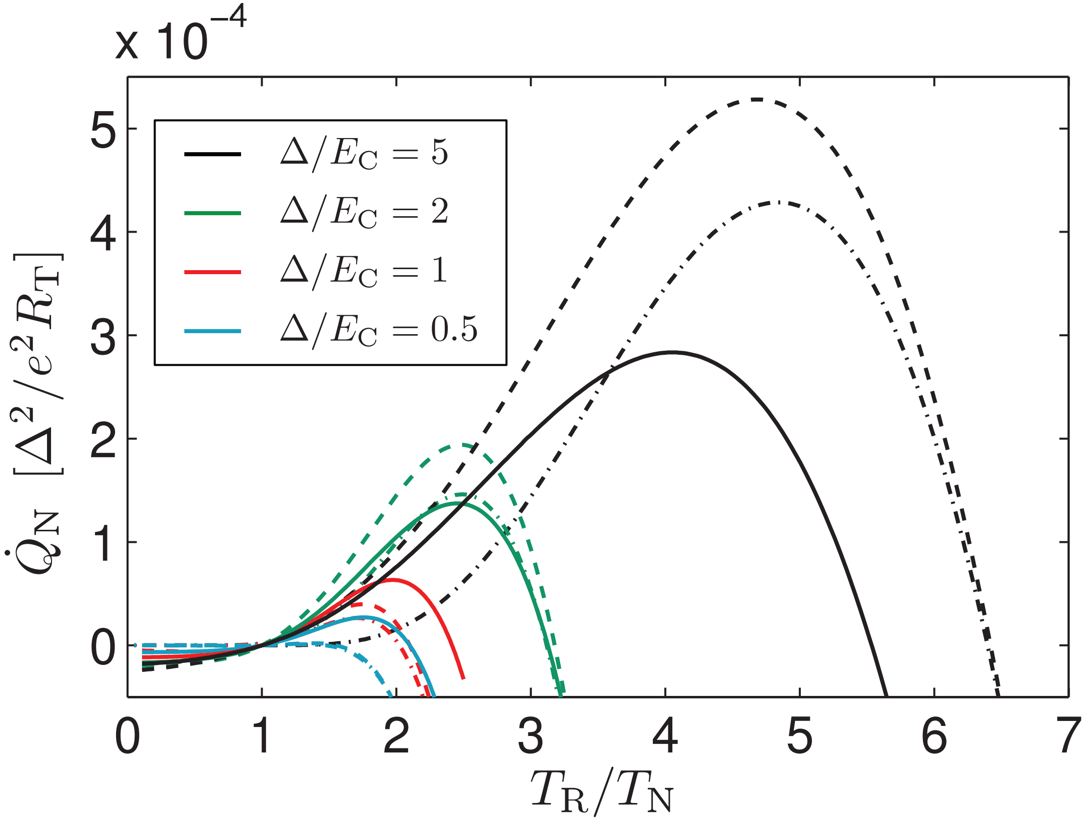
Smearing of the S DOS compared to the ideal BCS model

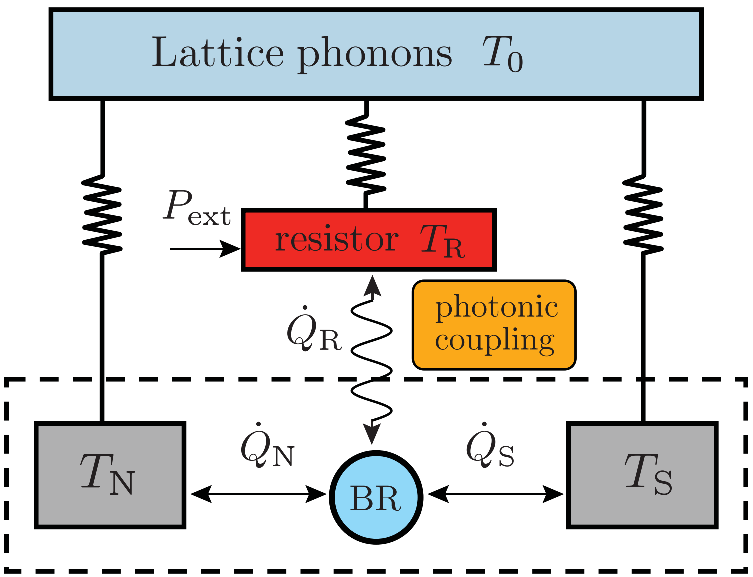
Fundamental ?

J. P. Pekola, T. T. Heikkila, A. M. Savin, and J. T. Flyktman, F. Giazotto, F. W. J. Hekking, PRL 92, 056804 (2004).

The Brownian refrigerator







Johnson-Nyquist noise of the resistor can bias a NIS cooler

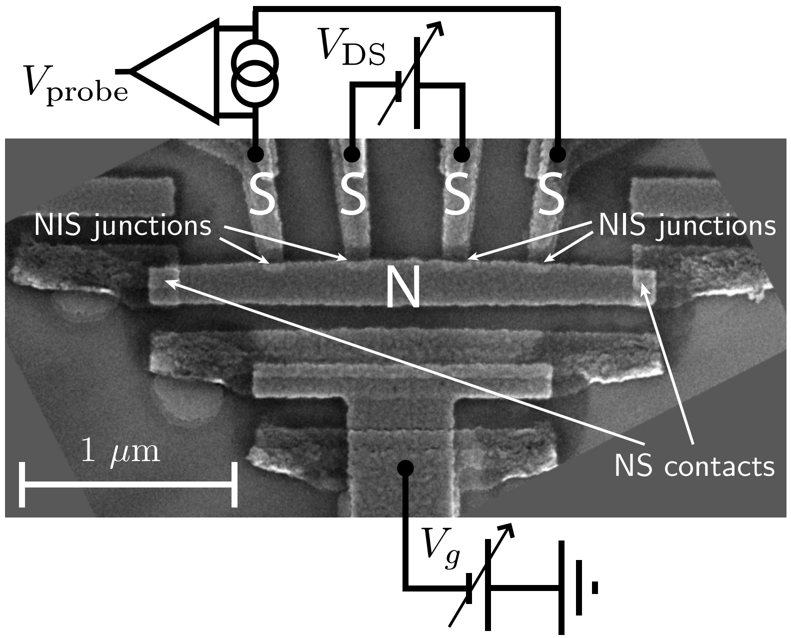
Cooling obtained if $k_B T \sim \Delta$.

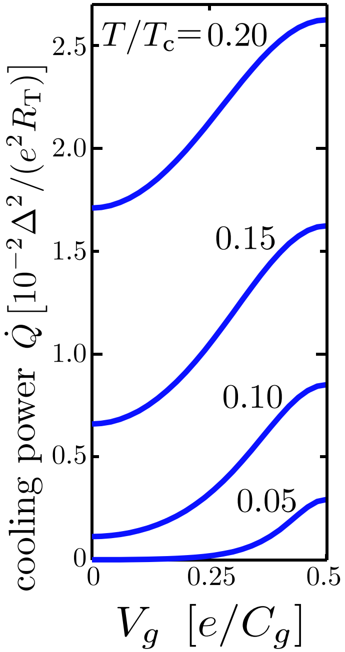
J. P. Pekola, F. W. J. Hekking, PRL 98, 210604 (2007)

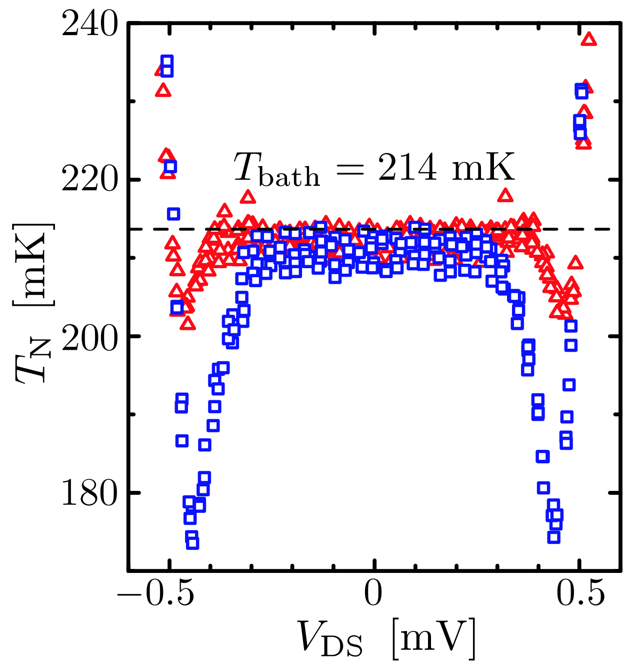
J. Peltonen, M. Helle, A. V. Timofeev, P. Solinas, F.W.J. Hekking, J. P. Pekola, PRB 84, 144505 (2011)

The heat transistor

A SINIS SET equipped with NIS probes





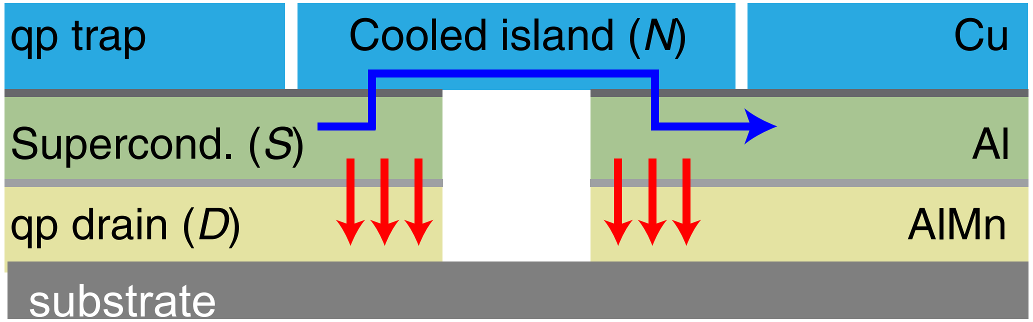


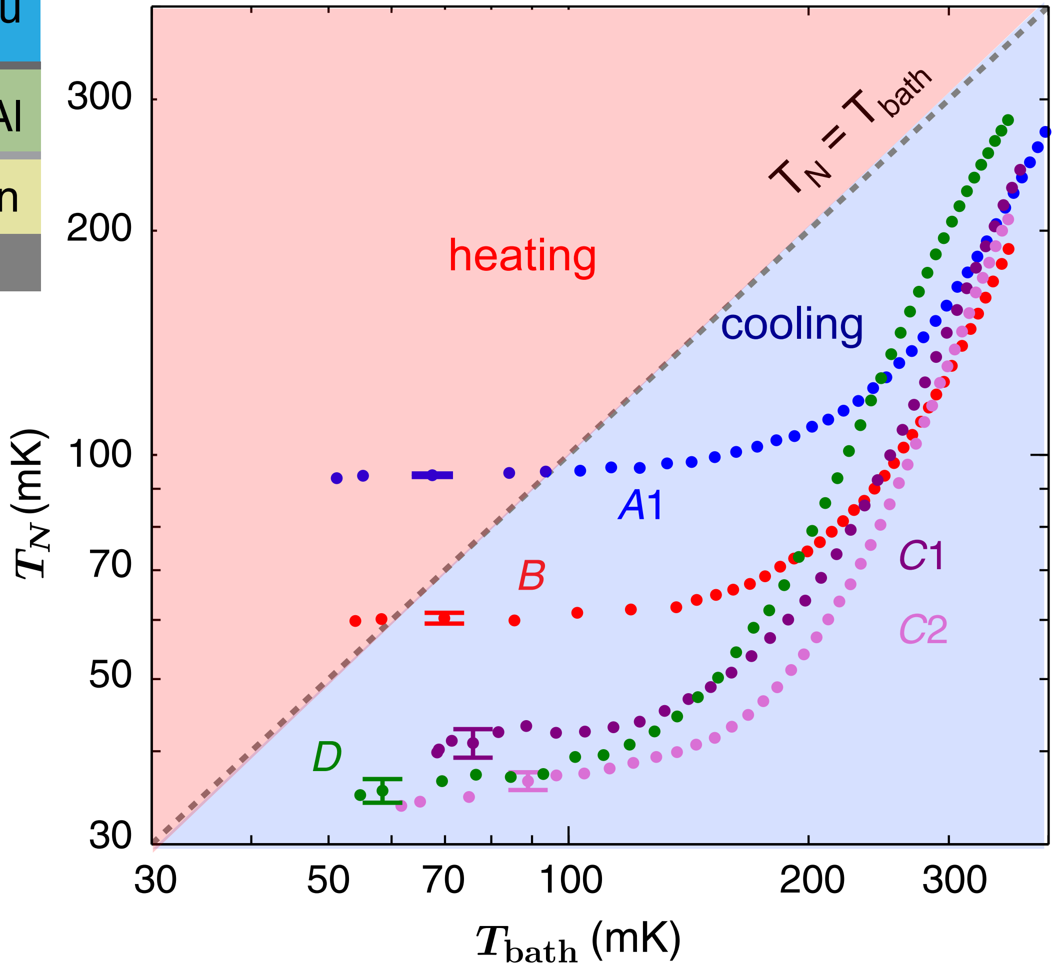
Charge and heat current both controlled by the gate.

NIS act as thermometers although charge number distribution in N varies

O.-P. Saira, M. Meschke, F. Giazotto, A. M. Savin, M. Mottonen, J. P. Pekola, PRL 99, 027203 (2007)

Electronic cooling down to very low temperature





No direct metal / substrate contact.

Quasi-particle trap below the S leads.

Minimum temperature T_N down to 30 mK, up to nW power.

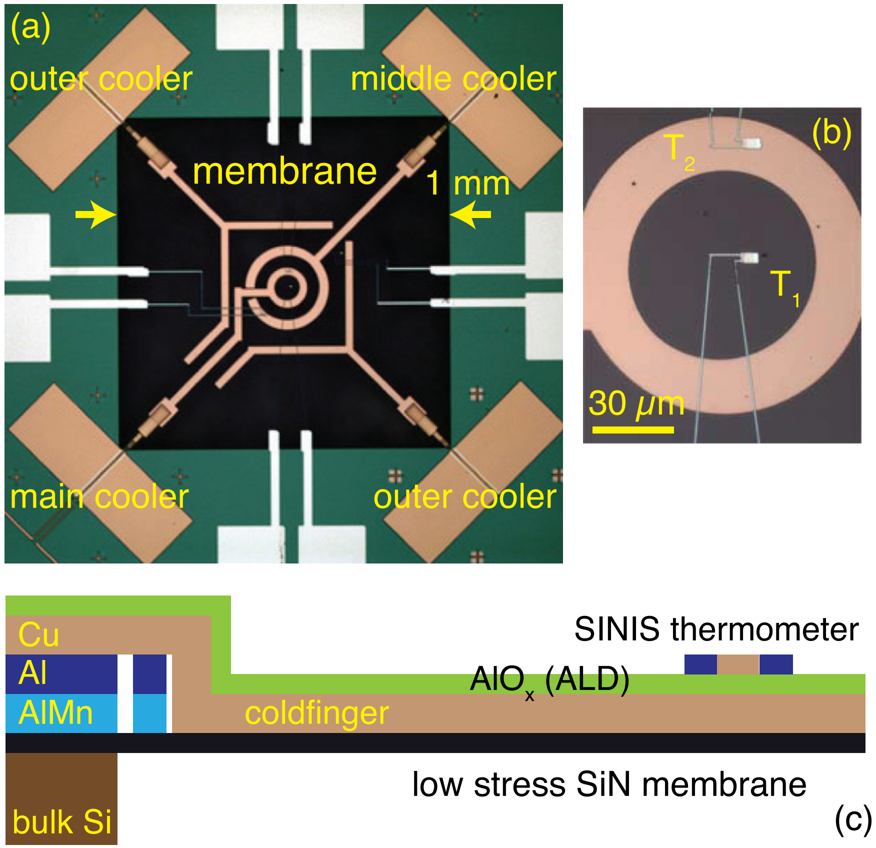
Phonon cooling improves efficiency

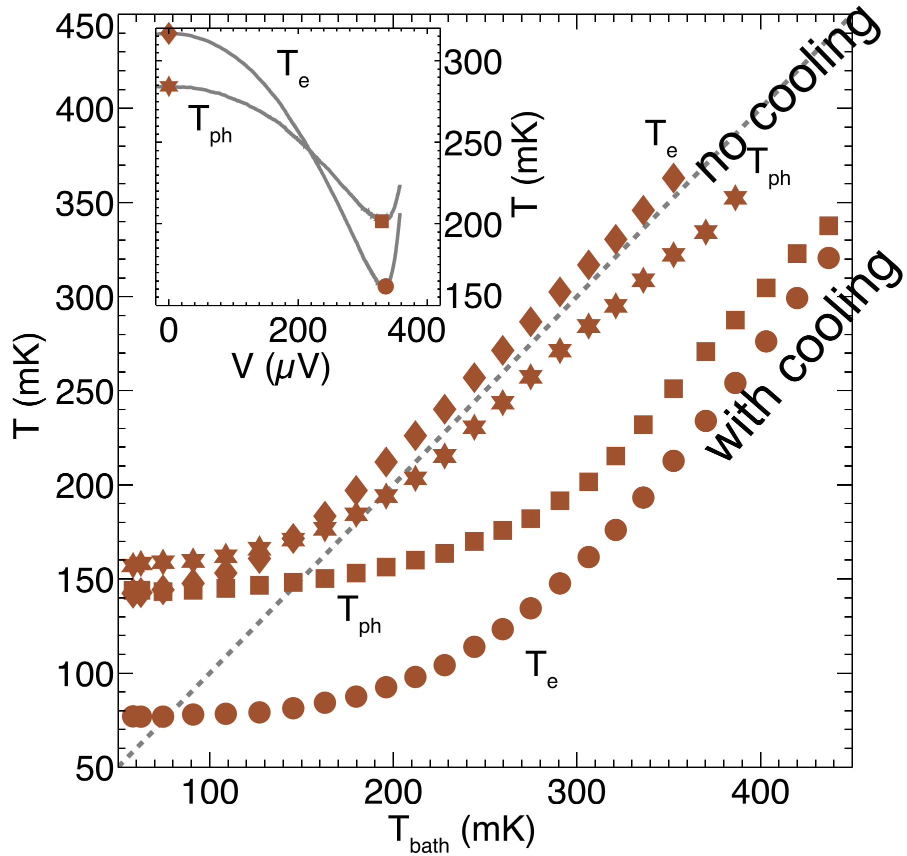
H. Q. Nguyen, M. Meschke, H. Courtois, and J. P. Pekola, PRAppl 2, 054001 (2014).

A robust platform cooled by superconducting electronic refrigerators

Membrane cooled by NIS coolers in an onion-like geometry

Unperforated and alumina-covered membrane





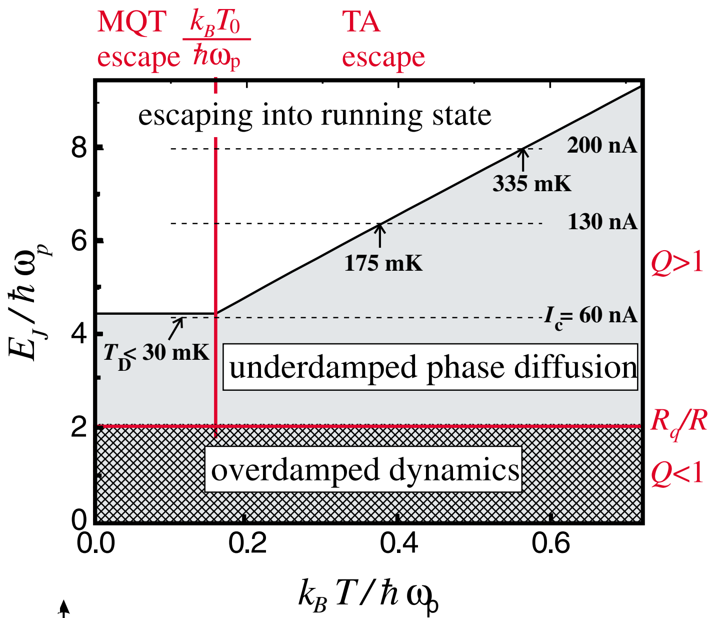
H. Q. Nguyen, M. Meschke, and J. P. Pekola, APL 106, 012601 (2015).

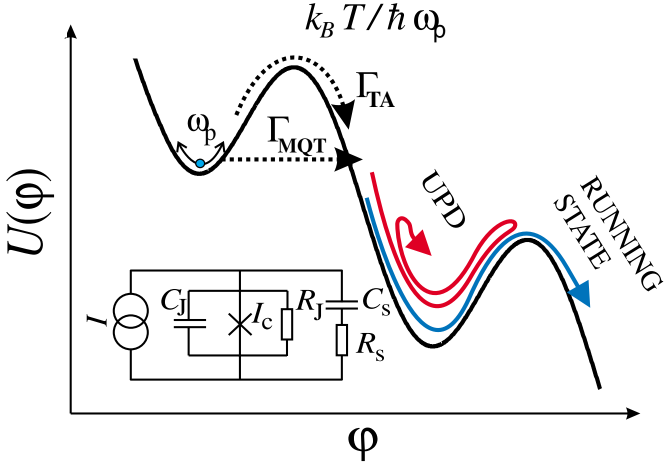
SQUIDs

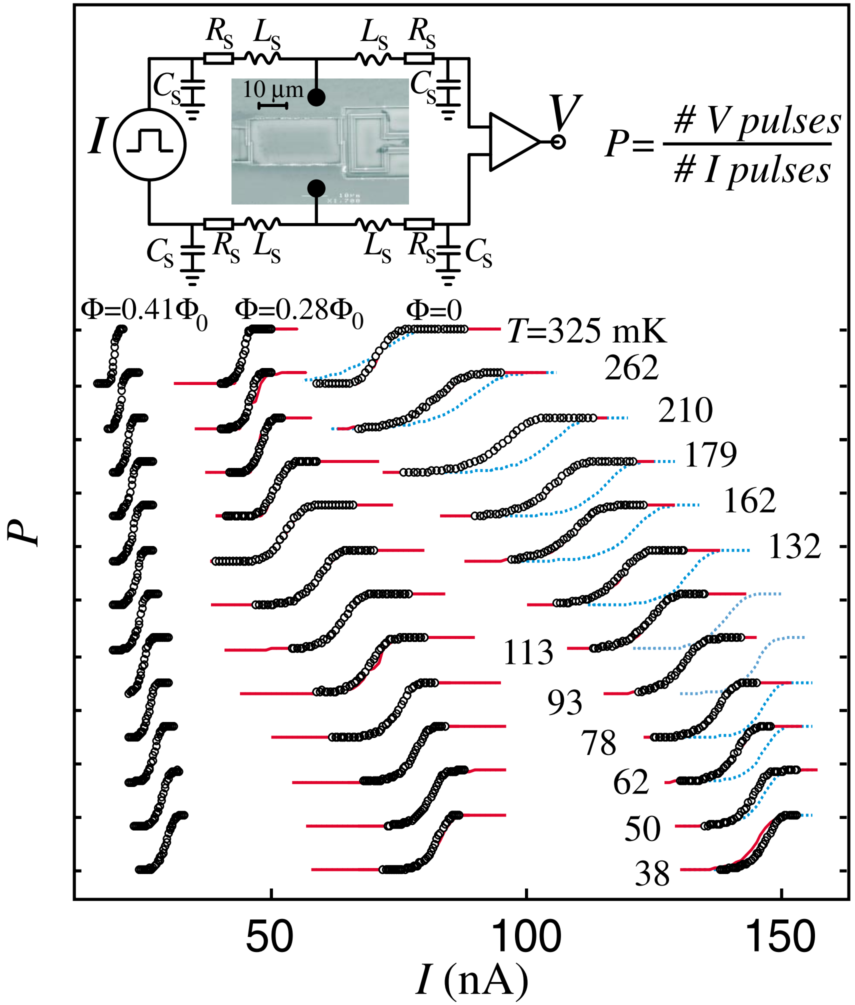
Underdamped phase diffusion in a SQUID

Phase variable in a SQUID = particle in a tilted washboard potential

Escape through thermal activation (TA), macroscopic quantum tunneling (MQT), and underdamped phase diffusion.





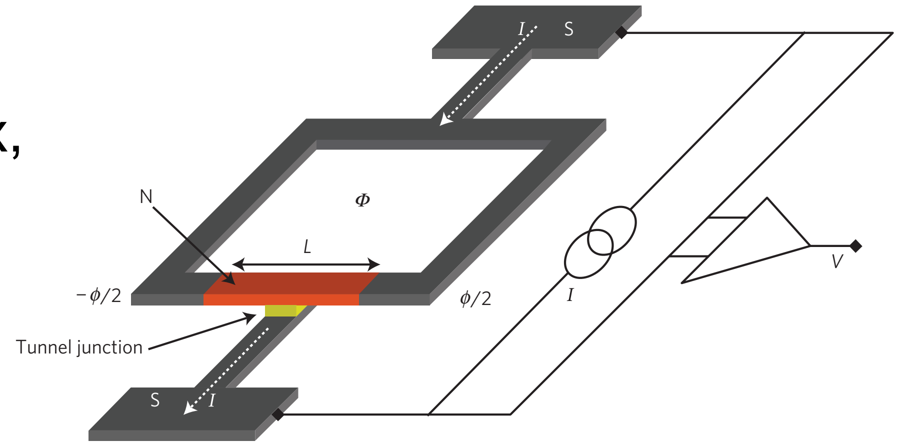


J. M. Kivioja, T. E. Nieminen, J. Claudon, O. Buisson, F. W. J. Hekking, and J. P. Pekola, PRL 94, 247002 (2005)

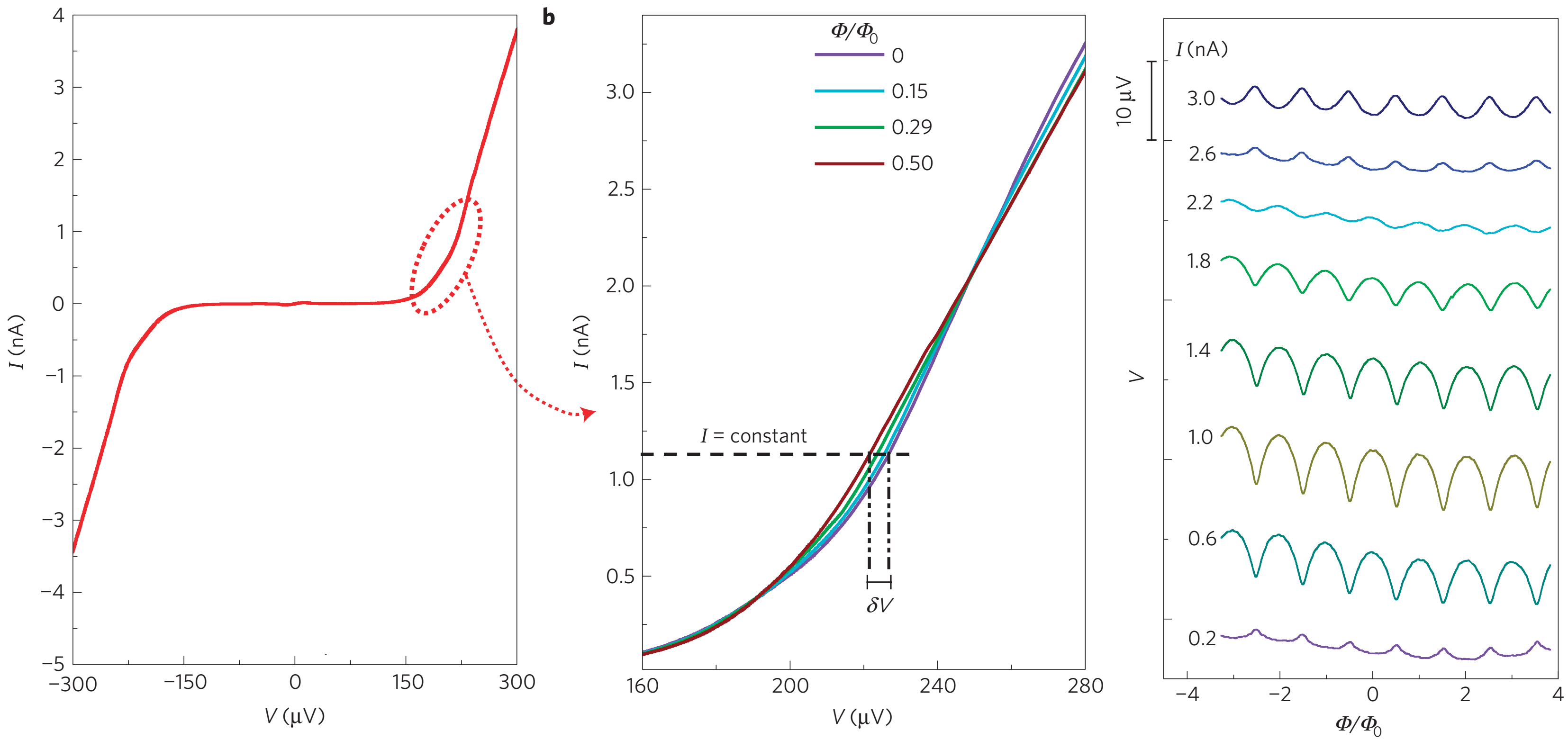
Superconducting quantum interference proximity transistor

Proximity induced gap modulated by a flux, probed a tunnel junction.

Large flux-to-voltage response



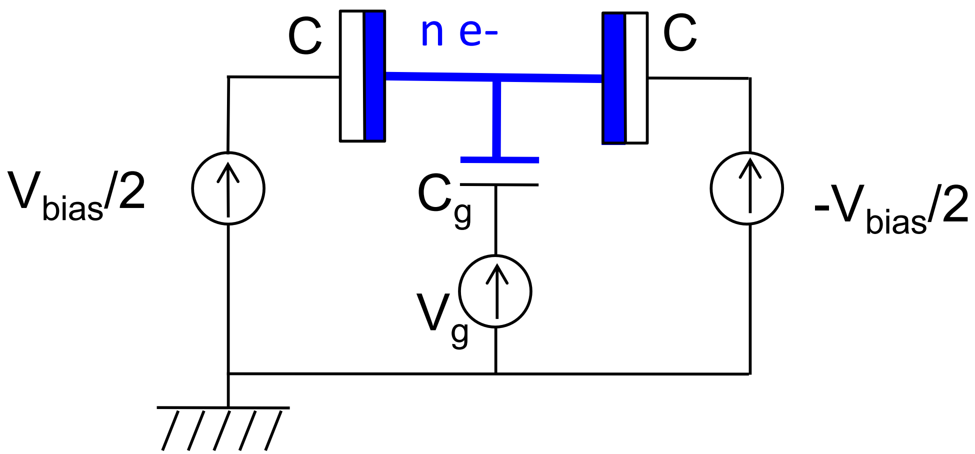
F. Giazotto, J. T. Peltonen, M. Meschke and J. P. Pekola, Nature Phys. 6, 254 (2010)

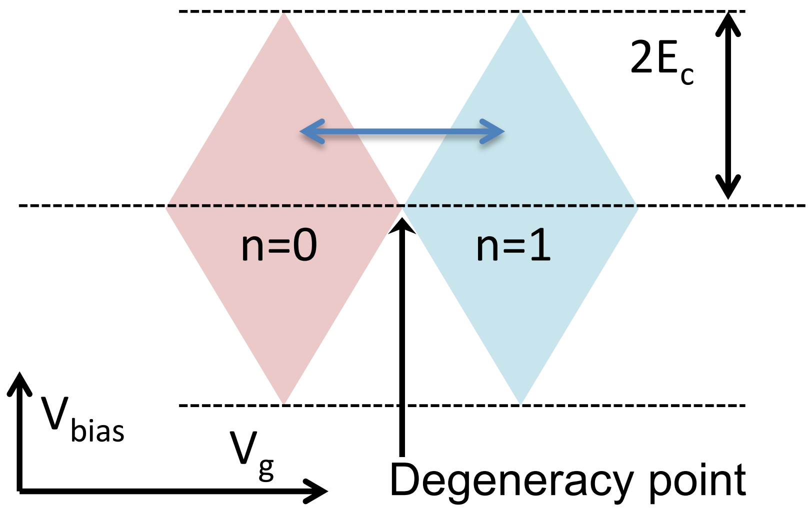


Turnstiles

A single electron transistor

A metallic island tunnel-coupled to two leads, under the influence of a gate.





Charging energy large compared to temperature : $E_c = \dfrac{e^2}{2C_\Sigma} >> k_B T$

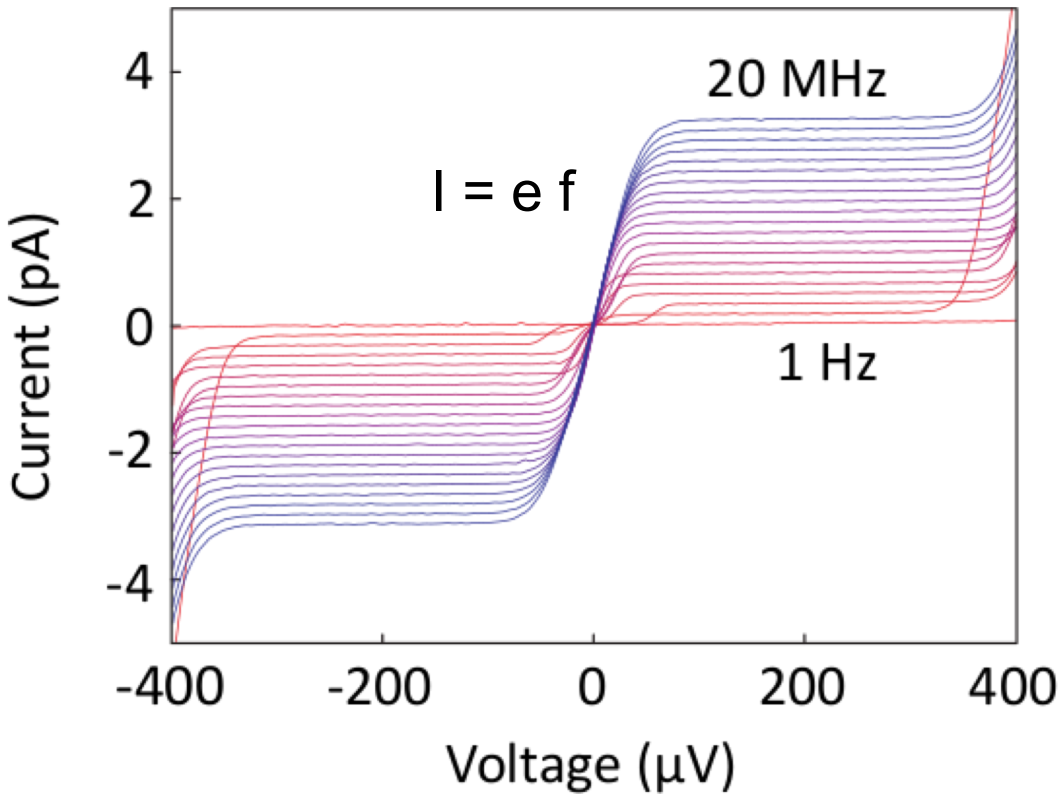
Tunnel resistance large compared to Klitzing resistance : $R_T >> R_K = \dfrac{h}{2\pi e^2}$

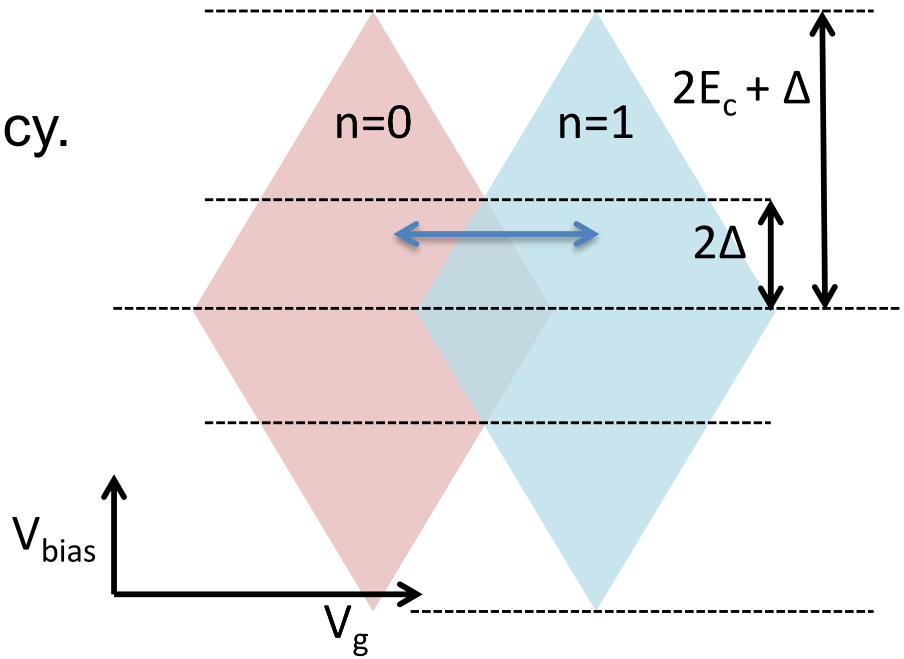
At degeneracy : only one channel for conduction, non-interacting

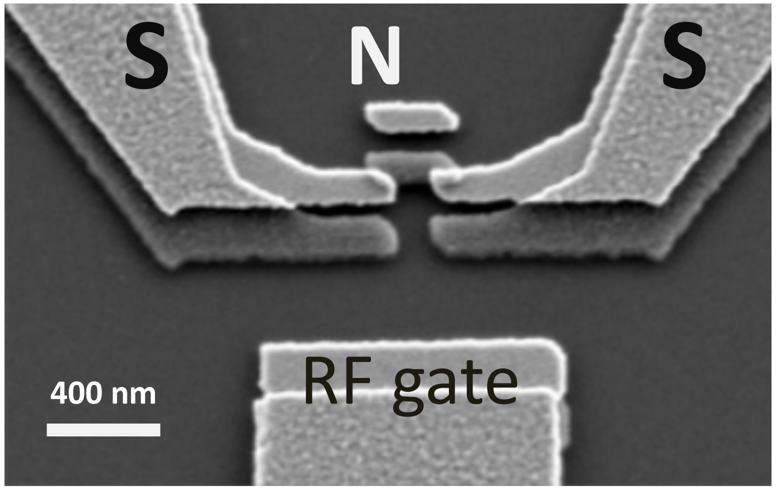
Gate oscillation between 0 and 1 states: I = e.f obtained but limited accuracy.

S-I-N-I-S turnstile

The sc gap makes the stability regions 0 and 1 overlap: improved turnstile accuracy.





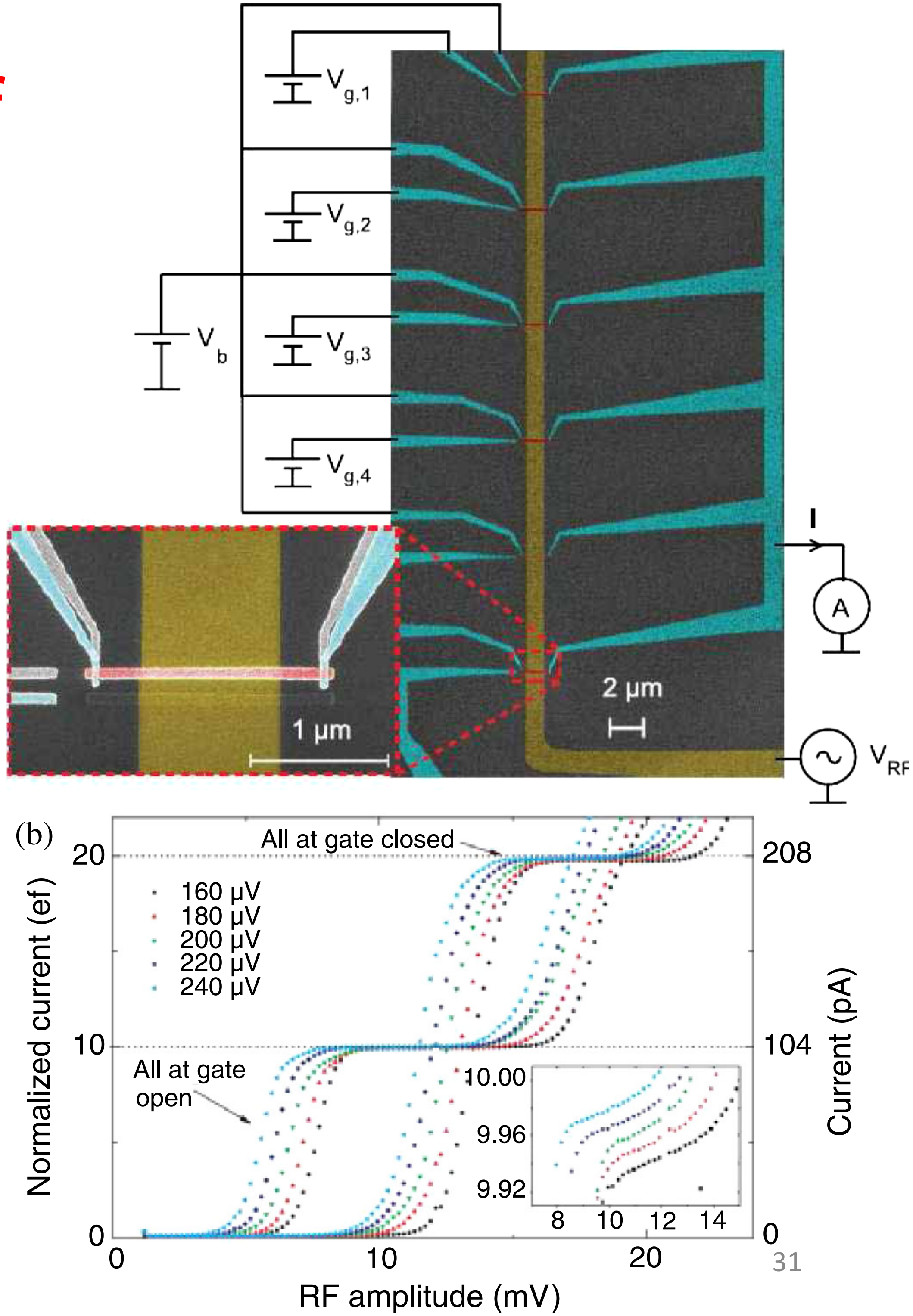


J. P. Pekola, J. J. Vartiainen, M. Mottonen, O.-P. Saira, M. Meschke, D. V. Averin, Nature Phys. 4, 120 (2008).

Parallel pumping of electrons

10 SINIS turnstiles in series
individual tuning by dc gates
a global rf gate

100 pA reached



V. F Maisi, Y. A. Pashkin, S. Kafanov, J. S. Tsai, J. P. Pekola, NJP 11, 113057 (2009).

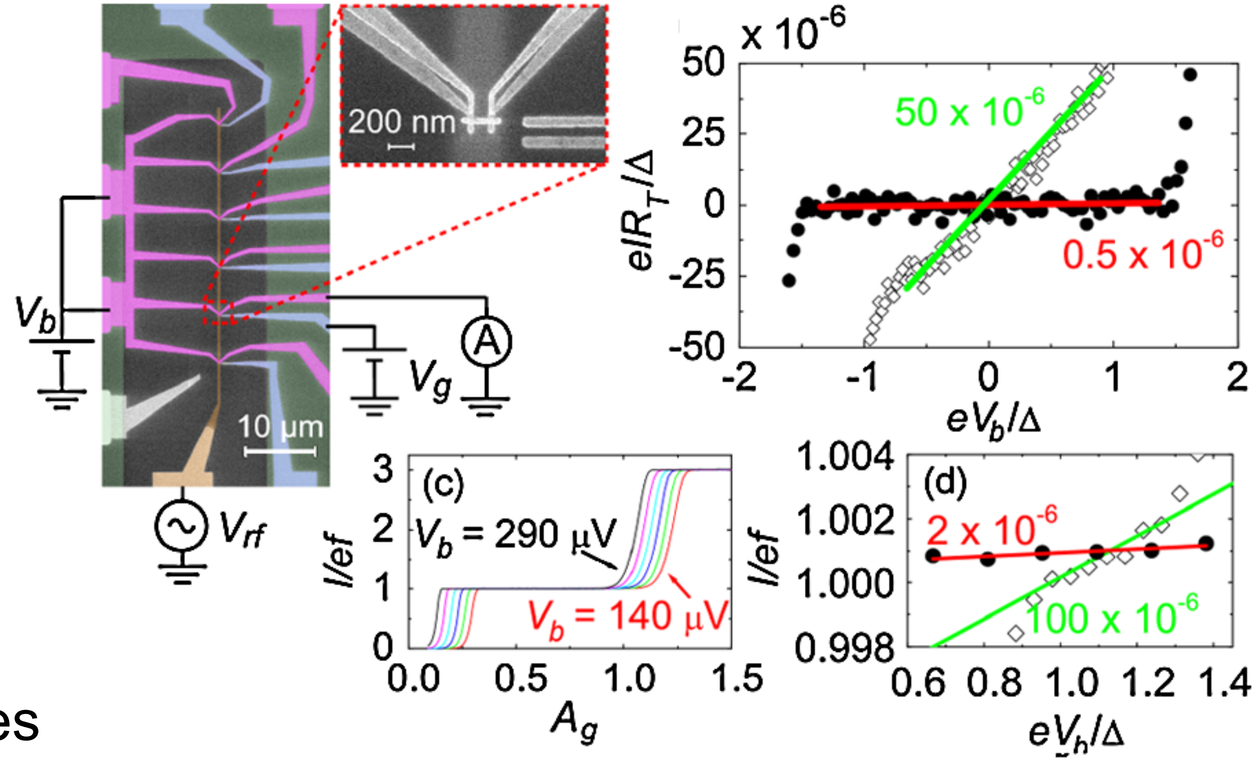
Environment-assisted tunneling

The electromagnetic environment drives the IV smearing of a NIS junction.

Equivalent to Dynes DoS

$$n(E) = \left| \Re\acute{e} \left(\frac{E/\Delta + i\sigma}{\sqrt{(E/\Delta + i\sigma)^2 - 1}} \right) \right|$$

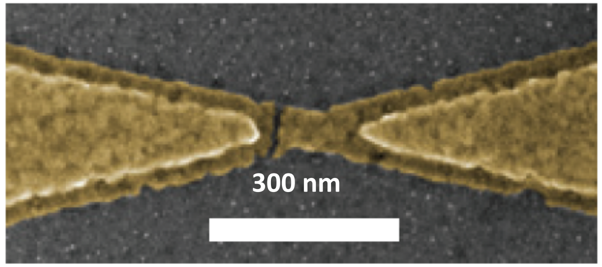
with: $\sigma = \frac{R}{R_Q} \frac{k_B T_{env}}{\Delta}$



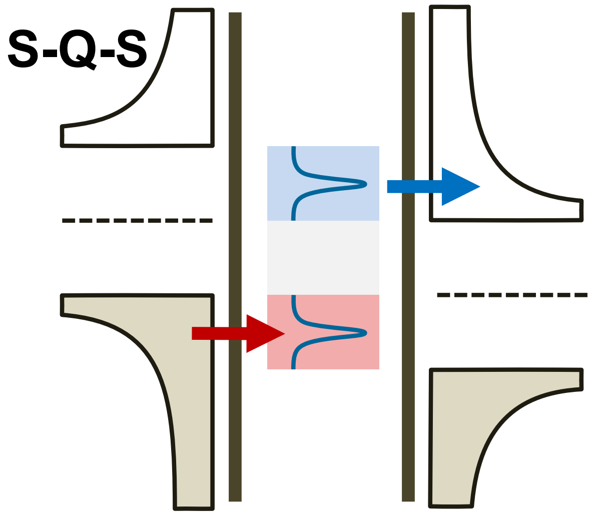
A ground plane enhances capacitive shunting and reduces sub-gap leakage.

J. P. Pekola, V. F. Maisi, S. Kafanov, N. Chekurov, A. Kemppinen, Yu. A. Pashkin, O.-P. Saira, M. Möttonen, and J. S. Tsai, PRL 105, 026803 (2010)

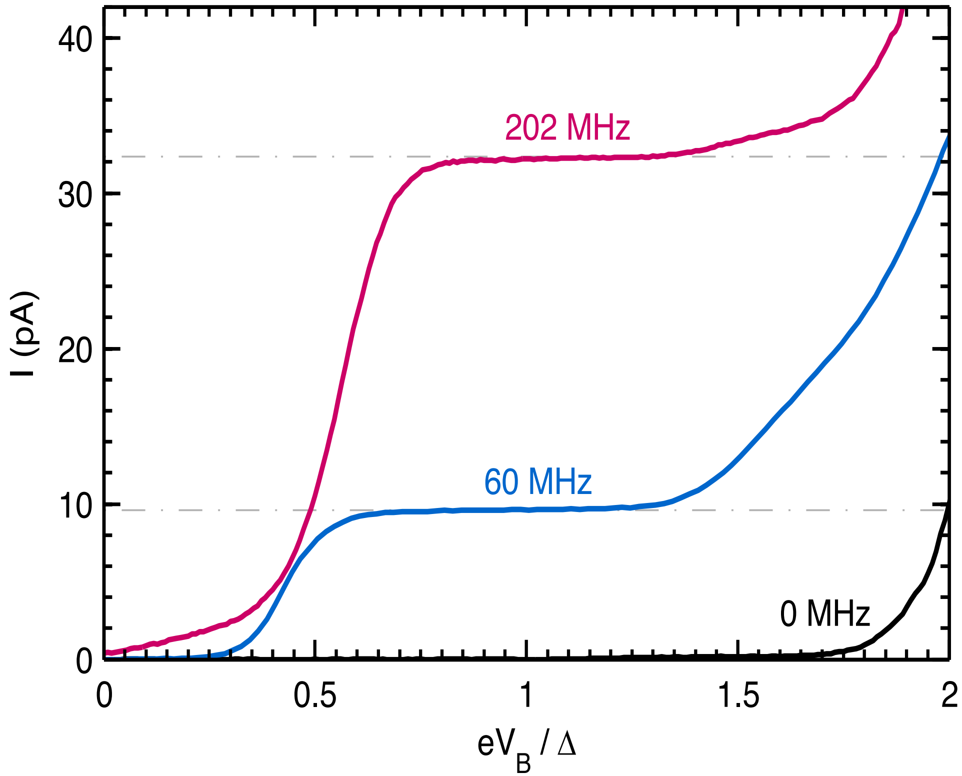
S-Q-S devices

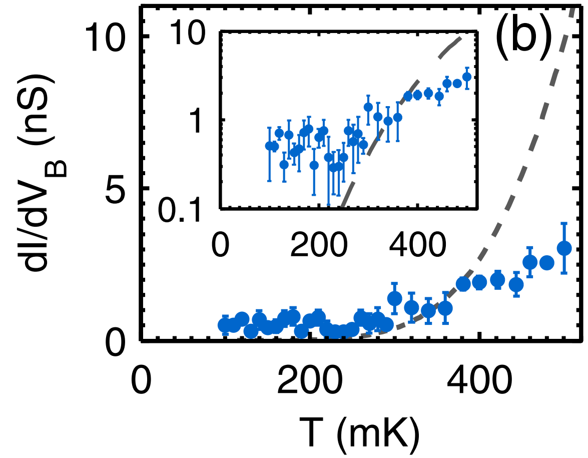


All-aluminum electromigration junctions
+ 5 nm Au nanoparticles



S-Q-S device with clear hierarchy of energy scales: $E_C \gg \delta \gg \Delta \gg k_B T > \gamma$





D. van Zanten, D. M. Basko, I. M. Khaymovich, J. P. Pekola, H. Courtois, C. B. Winkelmann, PRL 116, 166801 (2016).

Thermometry

Jukka's first paper

Physica 107B (1981) 337-338
North-Holland Publishing Company

FD 6

INTERCOMPARISON OF NBS AND HELSINKI TEMPERATURE SCALES IN THE MILLIKELVIN REGION

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Low Temperature Laboratory
Helsinki University of Technology
SF-02150 Espoo 15, Finland

and

R.J. Soulen, Jr.

National Bureau of Standards
Washington, D.C. 20234, USA

The Helsinki temperature scale, based on platinum NMR, is compared with the NBS noise and nuclear orientation temperature scale by means of three fixed points: the ^{3}He superfluid transition temperature at zero pressure (T_c) and the superconductive transition temperatures of samples of W and Be. The value for T_c on the NBS scale is found to be 1.025 mK, in close agreement with the Helsinki value of 1.04 mK. This result supports the liquid ^{3}He heat capacity data measured earlier at Helsinki.

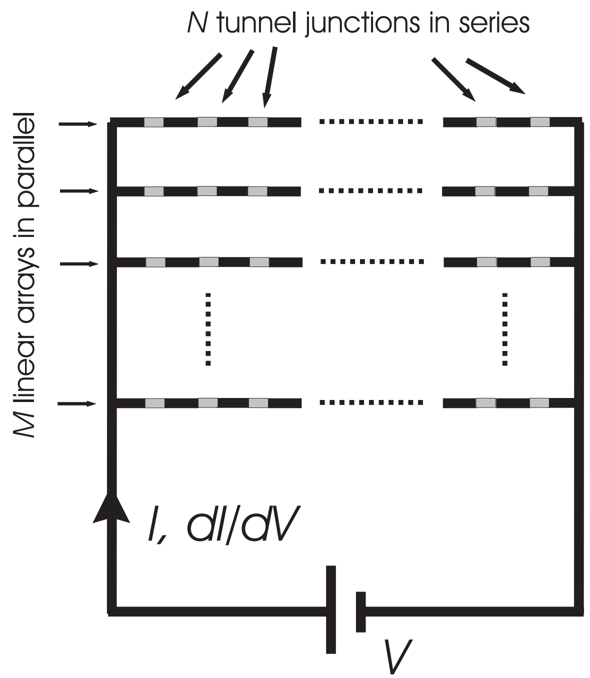
E. Lhota, M. T. Manninen, J. P. Pekola, A. T. Soinne, R. J. Soulen Jr, Physica B & C 107, 337 (1981)

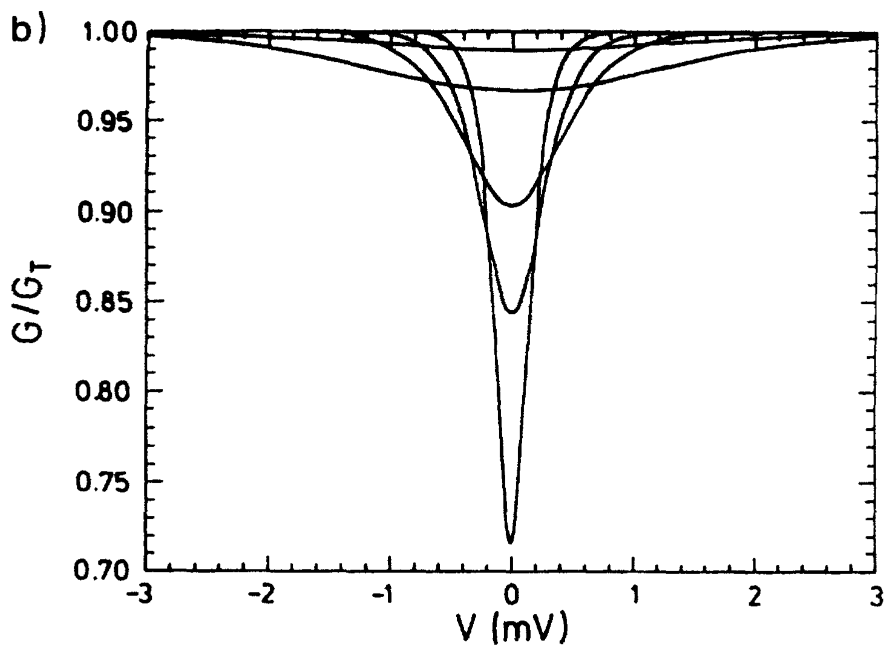
Coulomb blockade thermometers (CBT)

At degeneracy with $k_B T > E_c$, width of conductance peak determines T

Array: no high-order processes, large voltages, no effect of background charges

Sensitive to electron thermalization, but not to magnetic field





Sold as a commercial product by Nanoway, later Aivon

J. P. Pekola, K. P. Hirvi, J. P. Kauppinen, and M. A. Paalanen, PRL 73, 2903 (1994).
M. Meschke, J. P. Pekola, F. Gay, R. E. Rapp, and H. Godfrin, JLTP 134, 1119 (2004).
J. P. Pekola, J. K. Suoknuuti, J. P. Kauppinen, M. Weiss, P. v. d. Linden, A. G. M. Jansen, JLTP 128, 263 (2002).

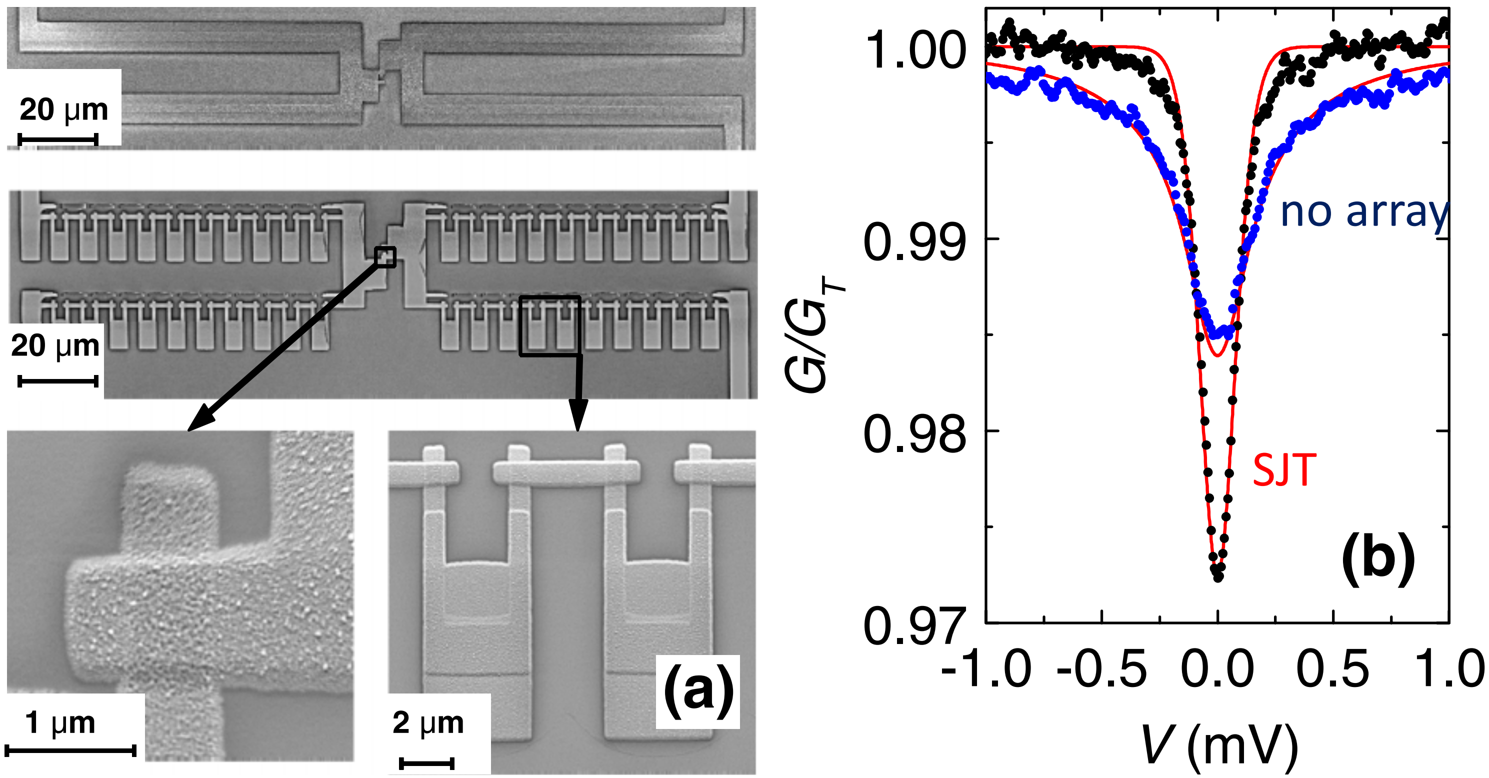
SET thermometry

Same primary response with a single junction biased through arrays:

$$V_{1/2} = 5.444\ k_B T \qquad \text{per junction}$$

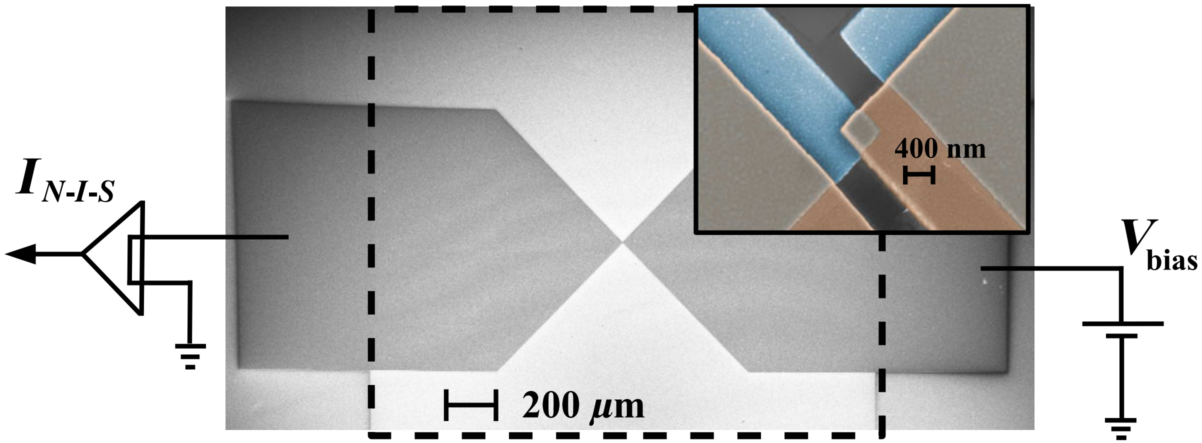
Avoids the problem of junctions parameter dispersion

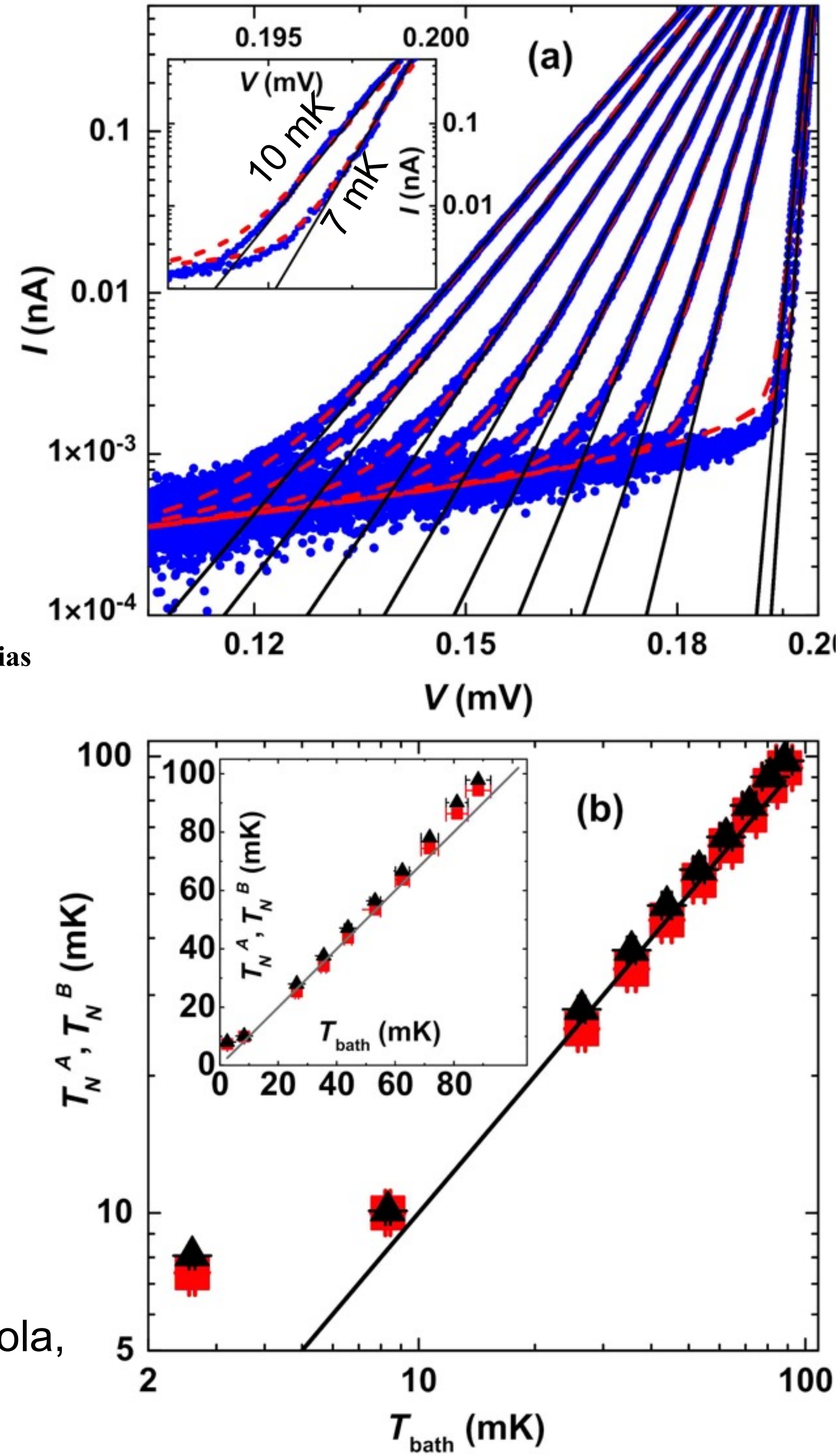
Protection from environmental noise



J. P. Pekola, T. Holmqvist, and M. Meschke, PRL 101, 206801 (2008).

Down to the milliKelvin range



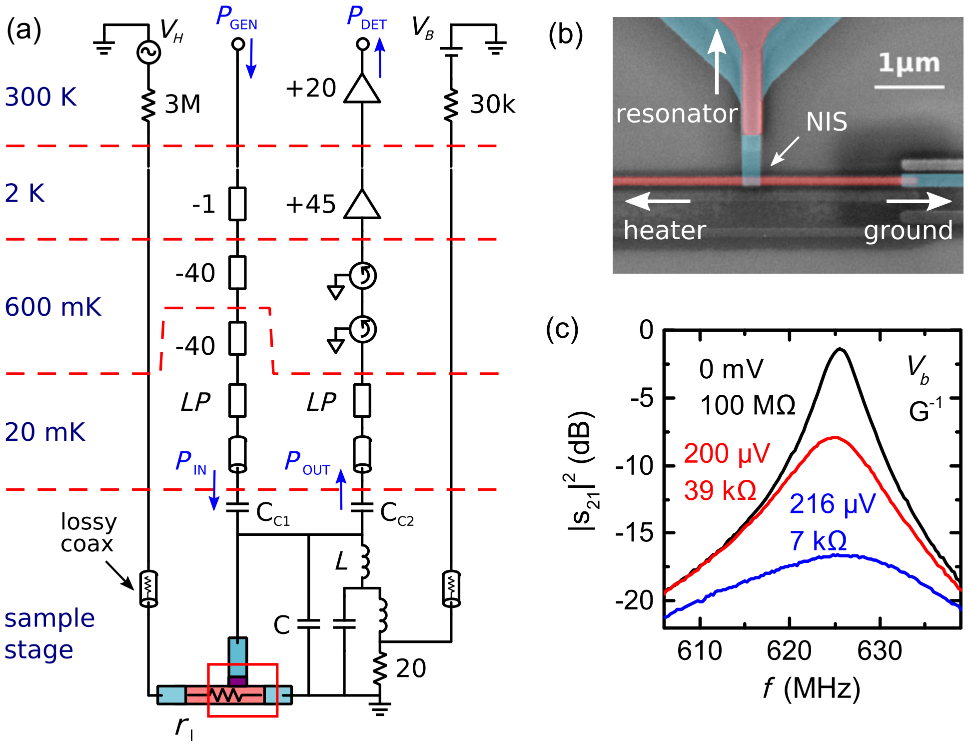


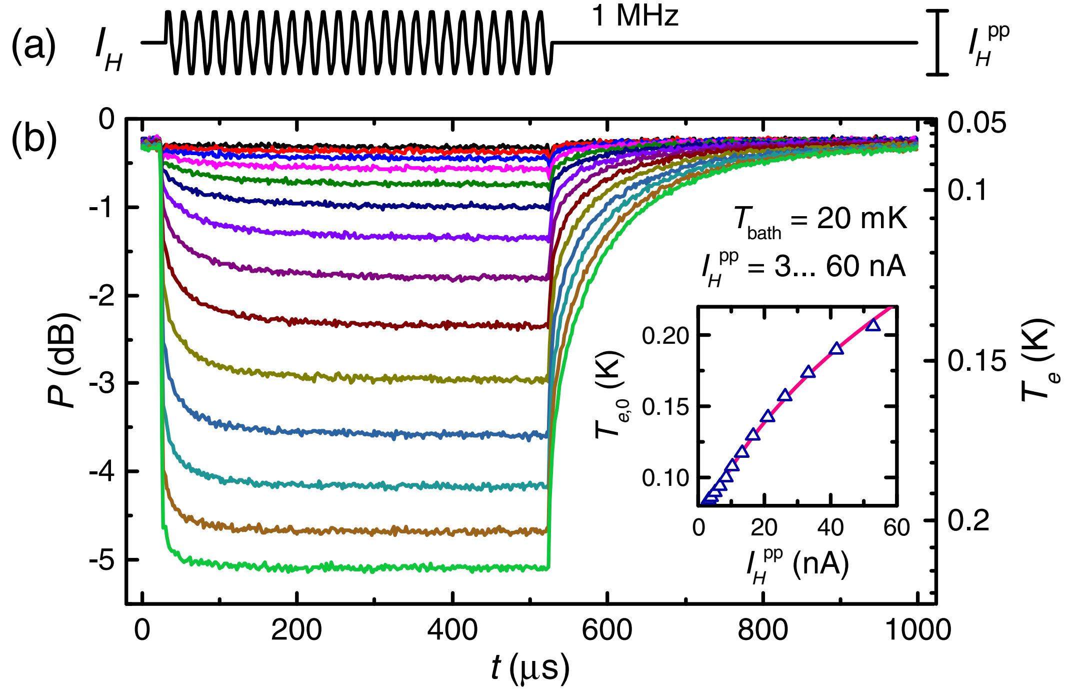
Heavy filtering, wide leads, ground plane

7.3 mK electronic temperature demonstrated

A. V. Feshchenko, L. Casparis, I. M. Khaymovich, D. Maradan, O.-P. Saira, M. Palma, M. Meschke, J. P. Pekola, and D. M. Zumbühl, PRAppl 4, 034001 (2015)

Fast electronic thermometry





Transmission of LC resonator coupled to a SIN junction

Achieves 90 $\mu\mathrm{K}/\sqrt{\mathrm{Hz}}$ noise-equivalent temperature with 10 MHz bandwidth

Single microwave photon can be detected

S. Gasparinetti, K. L. Viisanen, O.-P. Saira, T. Faivre, M. Arzeo, M. Meschke, and J. P. Pekola, PRAppl 3, 014007 (2015)

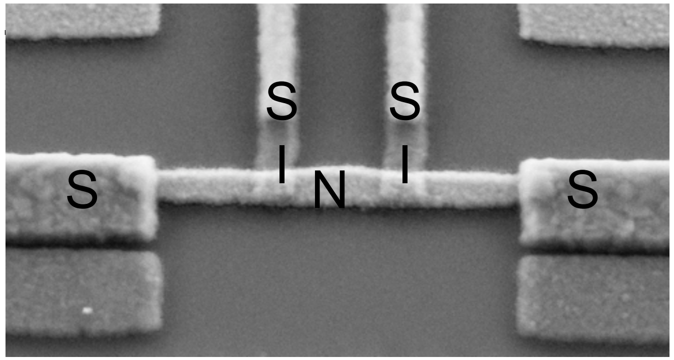
Heat transport

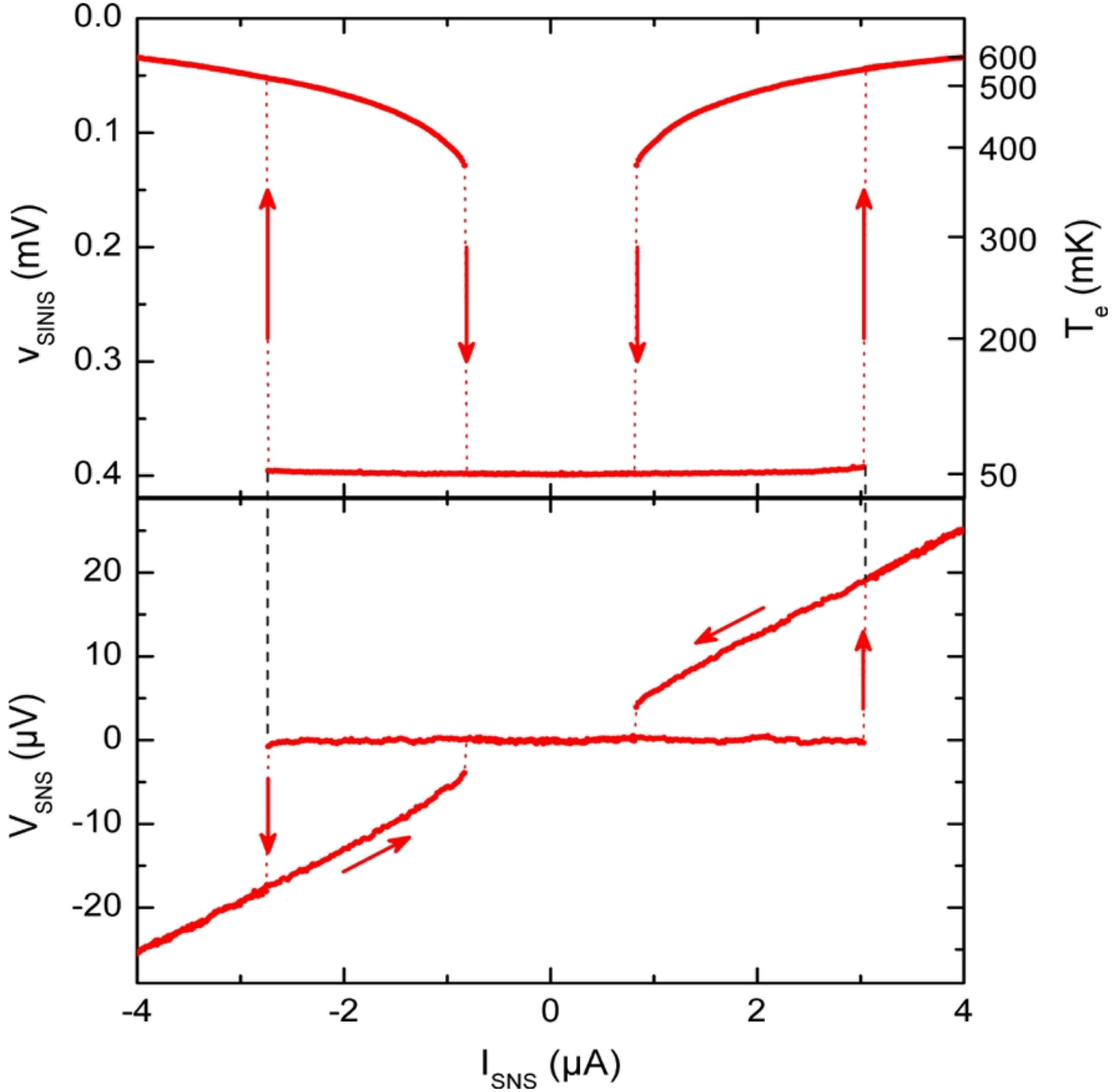
Origin of hysteresis in SNS Josephson junction

Hysteresis observed not described by RCSJ model since vanishing C.

The electron thermometer correlates to switching.

Thermal origin of the hysteresis.





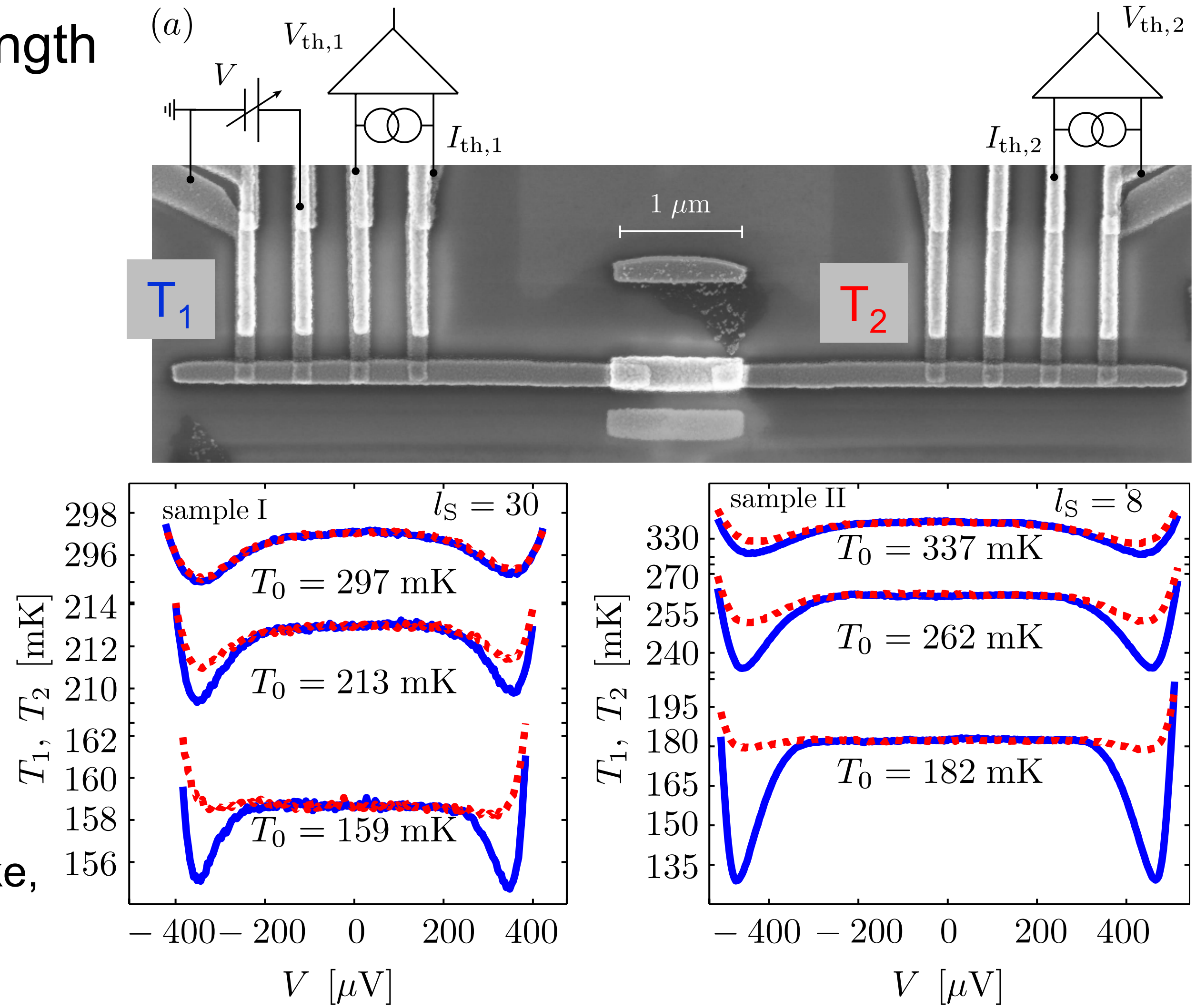
H. Courtois, M. Meschke, J. Peltonen and J. P. Pekola, Phys. Rev. Lett. 101, 067002 (2008).

Thermal conductance of S wires

A short S wire is not a good thermal insulator

Inverse proximity effect / quasi-particles not Andreev-reflected

Scale set by sc coherence length



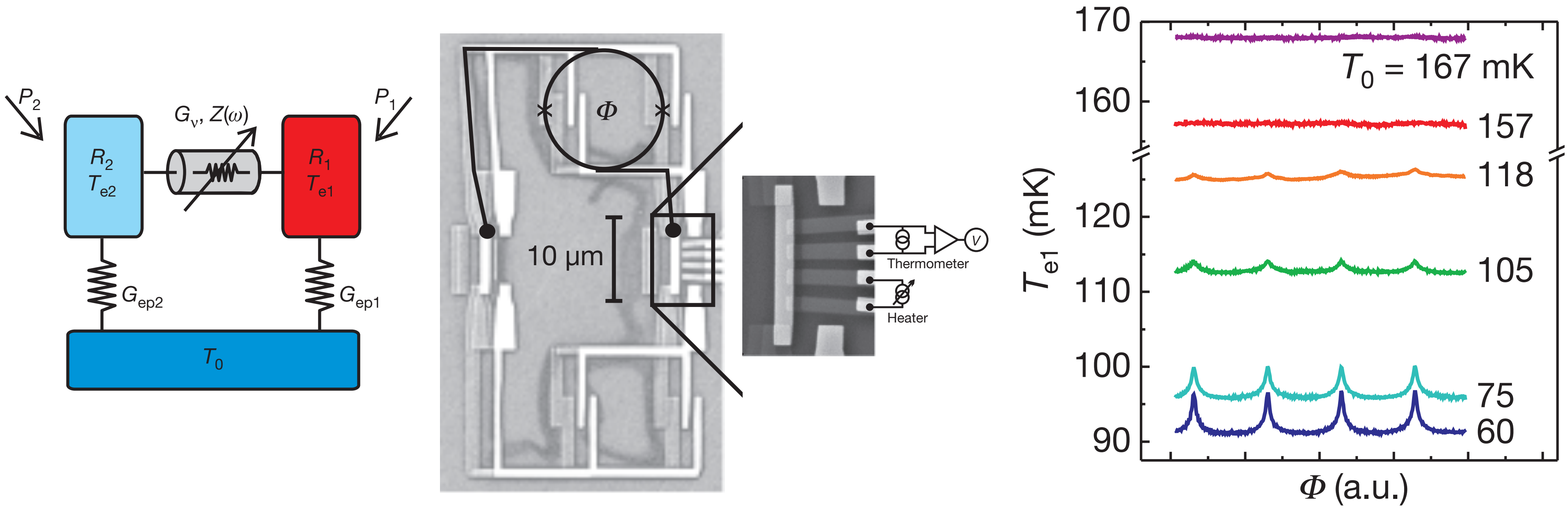
J. T. Peltonen, P. Virtanen, M. Meschke, J. V. Koski, T. T. Heikkila and J. P. Pekola, PRL 105, 097004 (2010)

Single mode heat conduction by photons

Photonic channel for the heat conduction = 1 quantum of conductance

Near-field regime

Heat transport between two electronic baths modulated by flux in a SQUID



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

Theory: heat transport through a SET

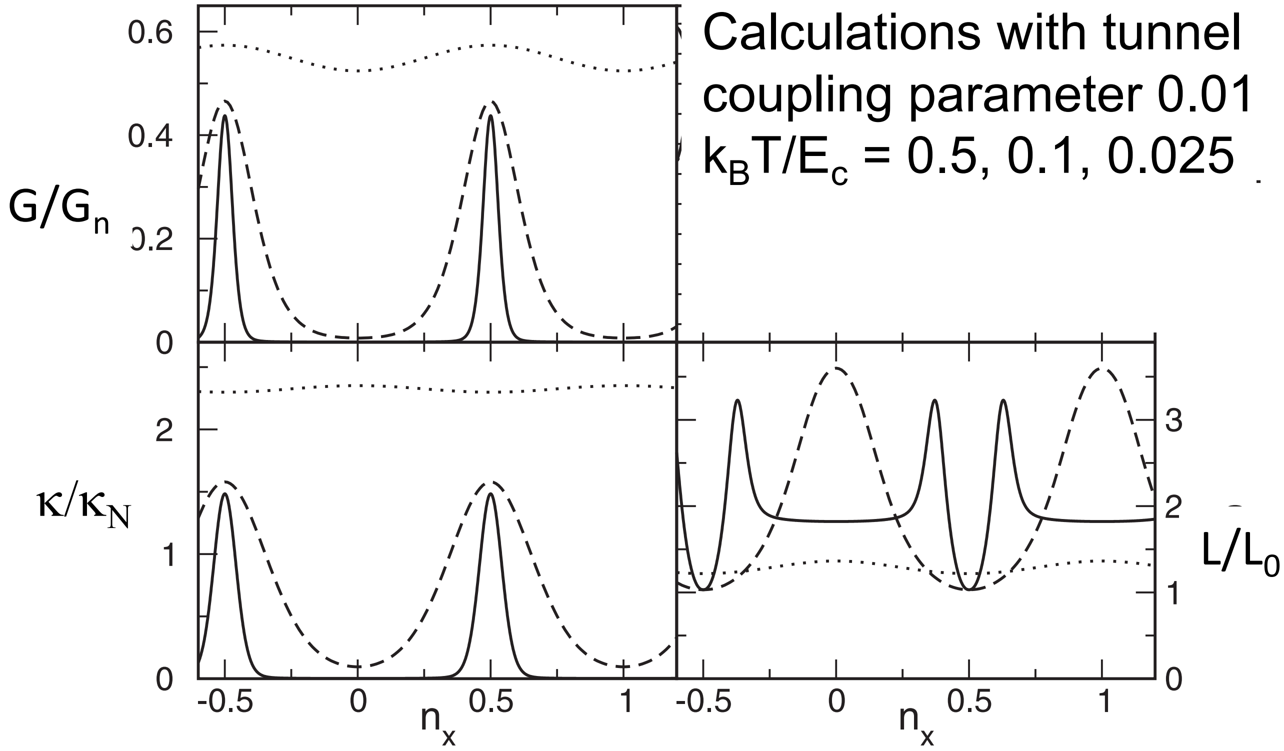
An electron carries a charge e and an energy about k_BT

Wiedemann-Franz law between charge and heat conductances:

$$L = \frac{\kappa}{GT} = L_0 = \frac{\pi^2 k_B^2}{3e^2}$$

WF law breaks in a SET since charging energy selects high-energy e-.

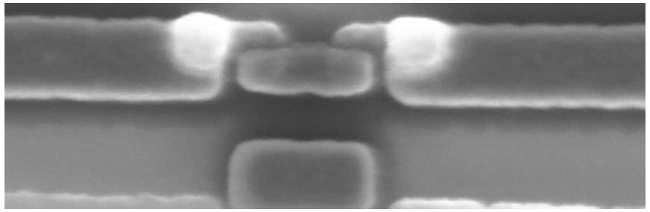
Co-tunneling at $k_BT < E_c/10$ selects low-energy e-.

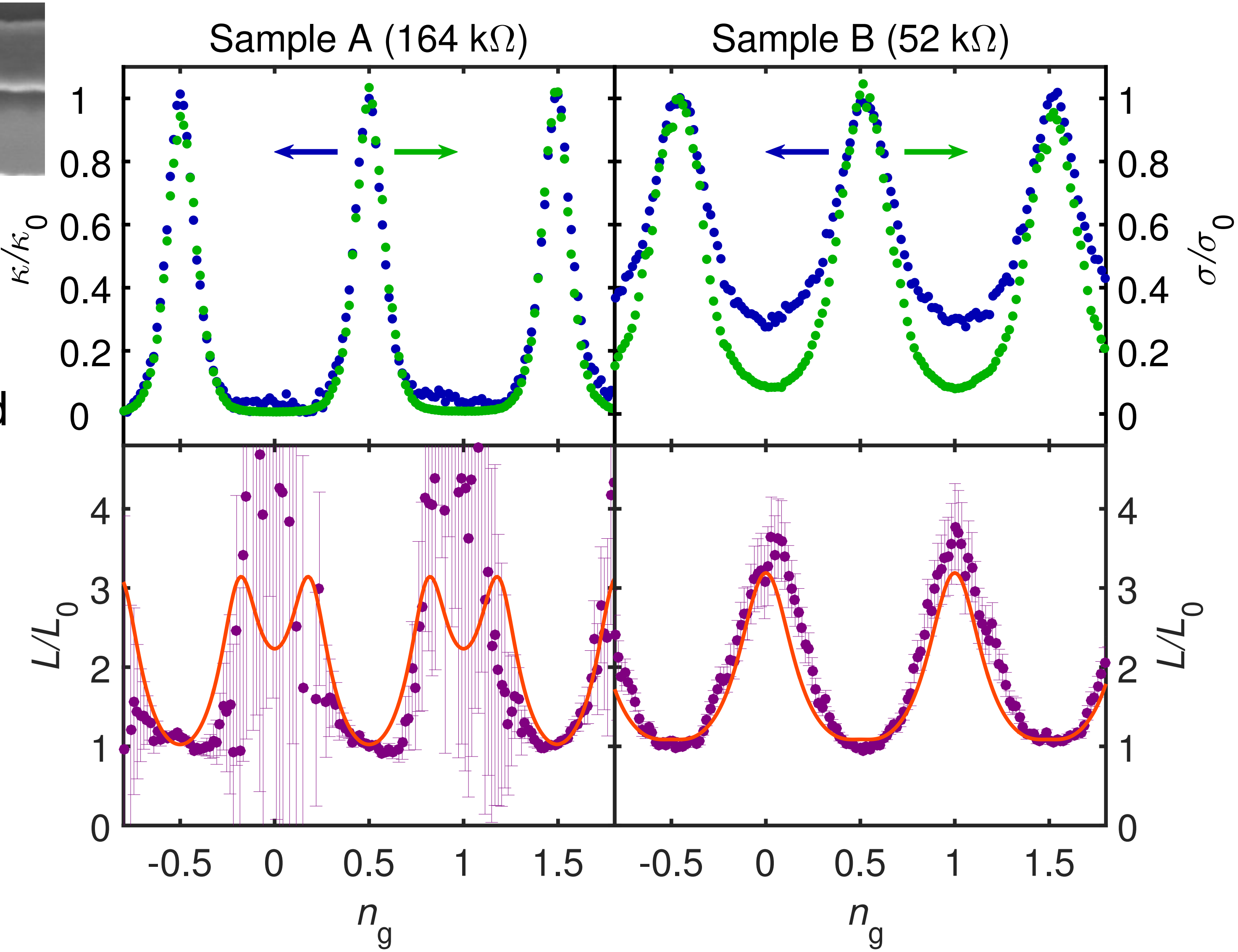


Calculations with tunnel coupling parameter 0.01
k_BT/E_c = 0.5, 0.1, 0.025

B. Kubala, J. König, and J. P. Pekola, Phys. Rev. Lett. 100, 066801 (2008).

Violation of the Wiedemann–Franz law





Drain electron bath cooled /heated, temperature monitored as a function of gate.

Assumption: WF law valid when gate open

$$\kappa = \frac{\dot{Q}_{SET}}{T_e - T_b}$$

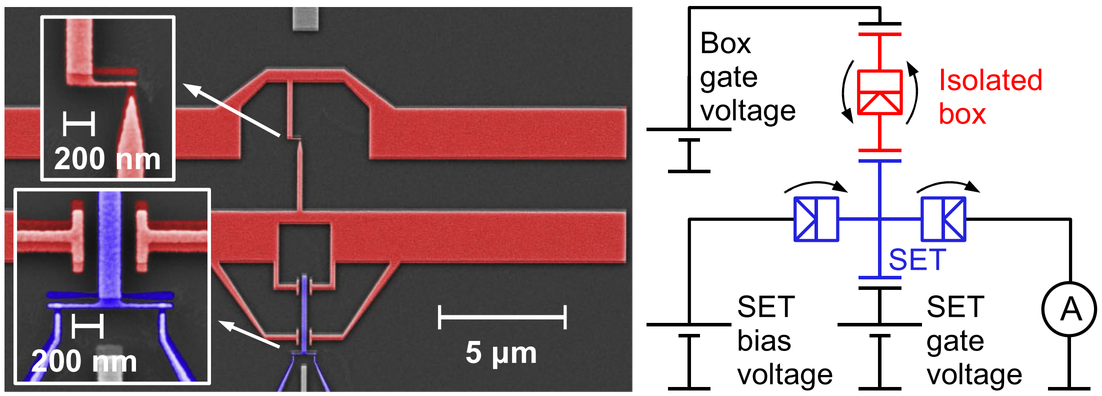
B. Dutta, J. Peltonen, D. S. Antonenko, M. Meschke, M. A. Skvortsov, B. Kubala, J. König, H. Courtois, C. B. Winkelmann, J. P. Pekola, PRL 119, 077701 (2017).

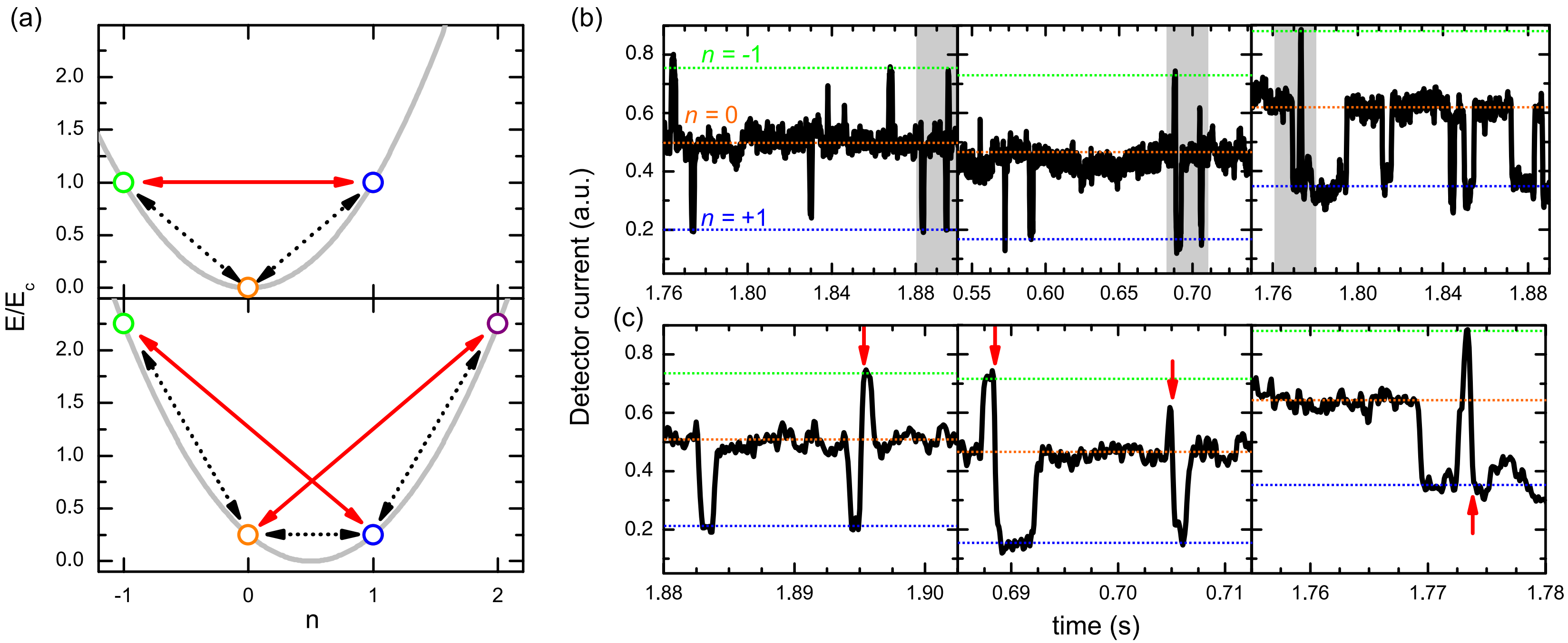
Towards quantum thermodynamics

Real-time observation of Andreev tunneling

A SET counts in real-time the electronic state of a NIS isolated electron box

Rate one order of magnitude higher than expected for a uniform barrier





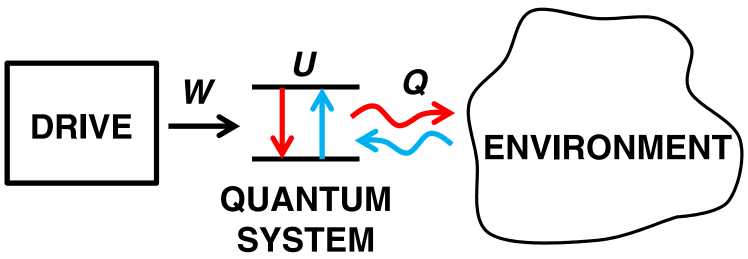
V. F. Maisi, O.-P. Saira, Yu. A. Pashkin, J. S. Tsai, D. V. Averin, J. P. Pekola, PRL 106, 217003 (2011)

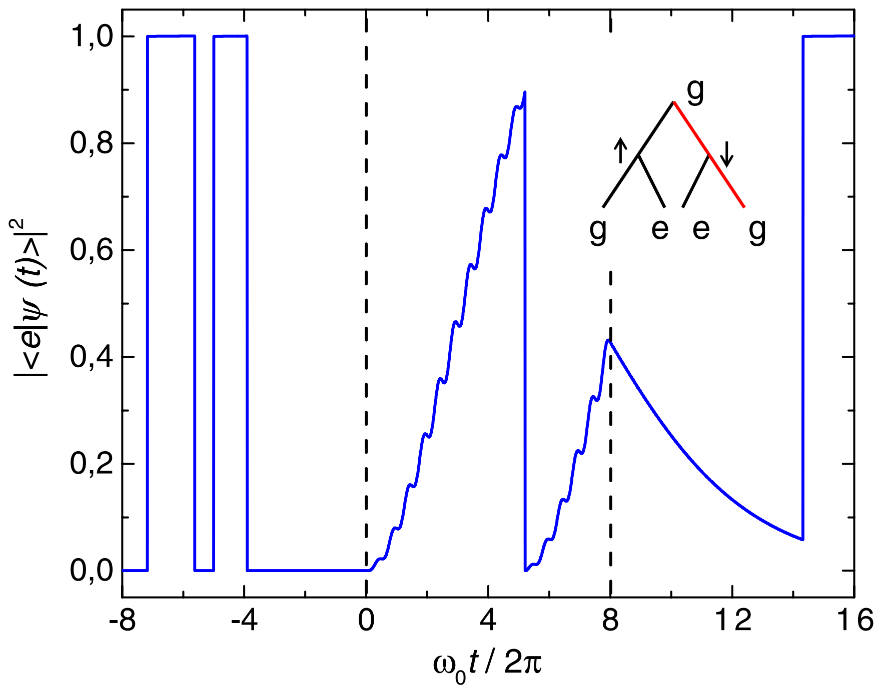
Quantum jumps

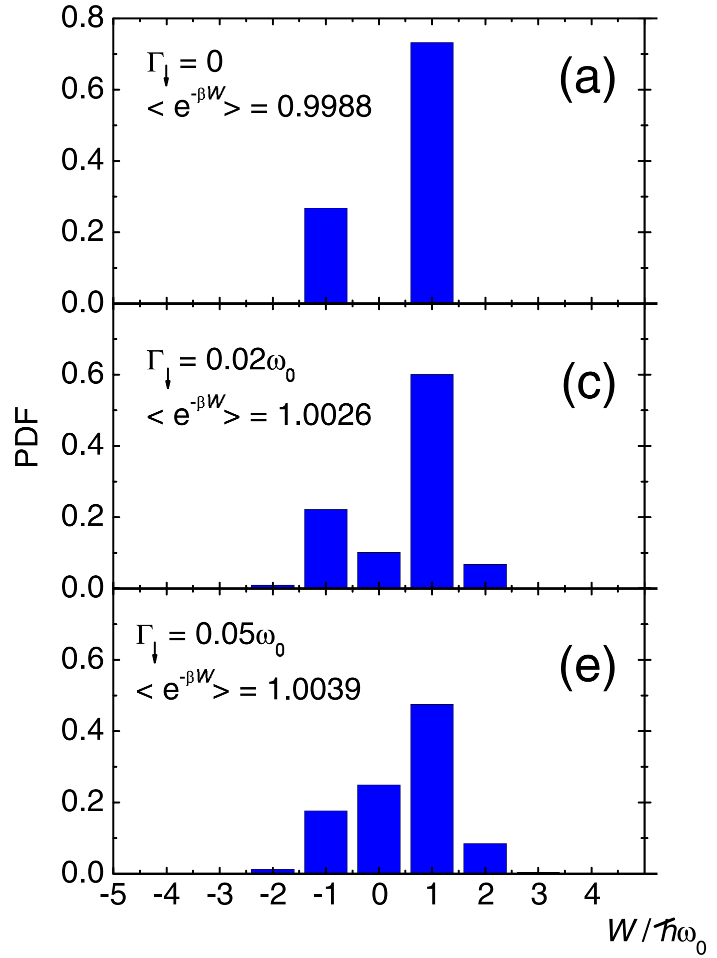
Discretization of time in elements during which 0 ; 1 or -1 is absorbed/emitted.

Detecting photons absorbed/emitted as a projective measurement

Work distribution and Jarzynski equality verified.

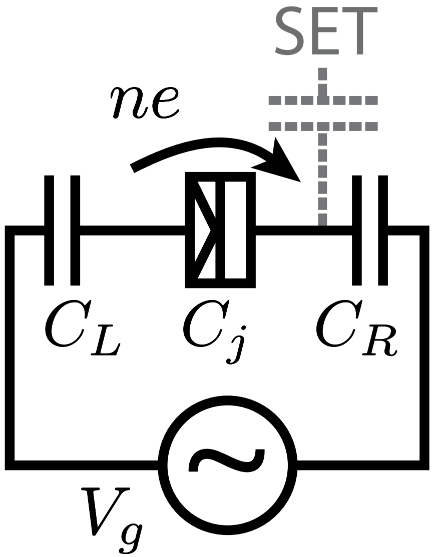


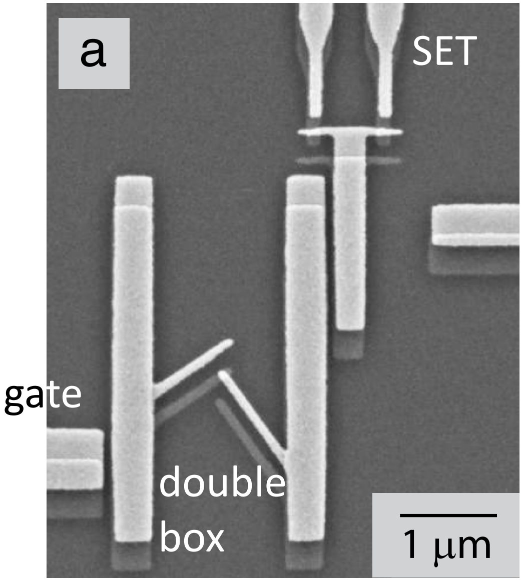


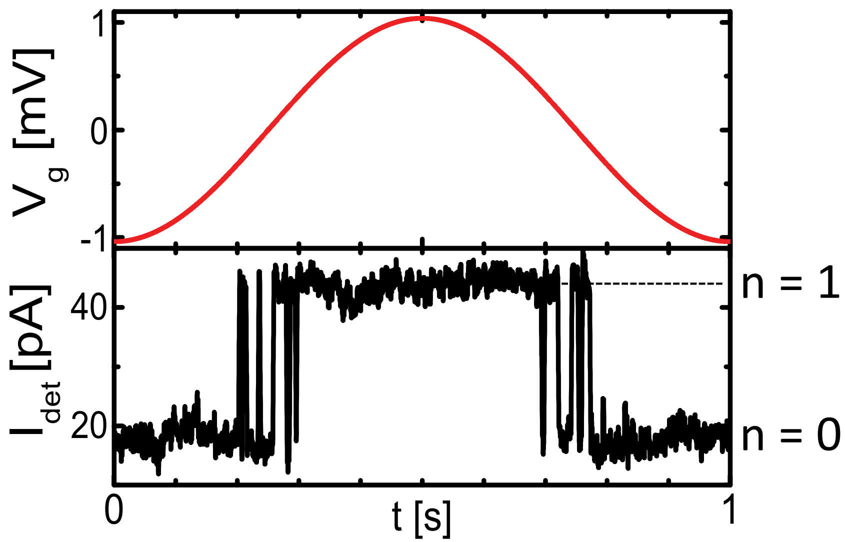


F. W. J. Hekking and J. P. Pekola, PRL 111, 093602 (2013)

Quantum thermodynamics





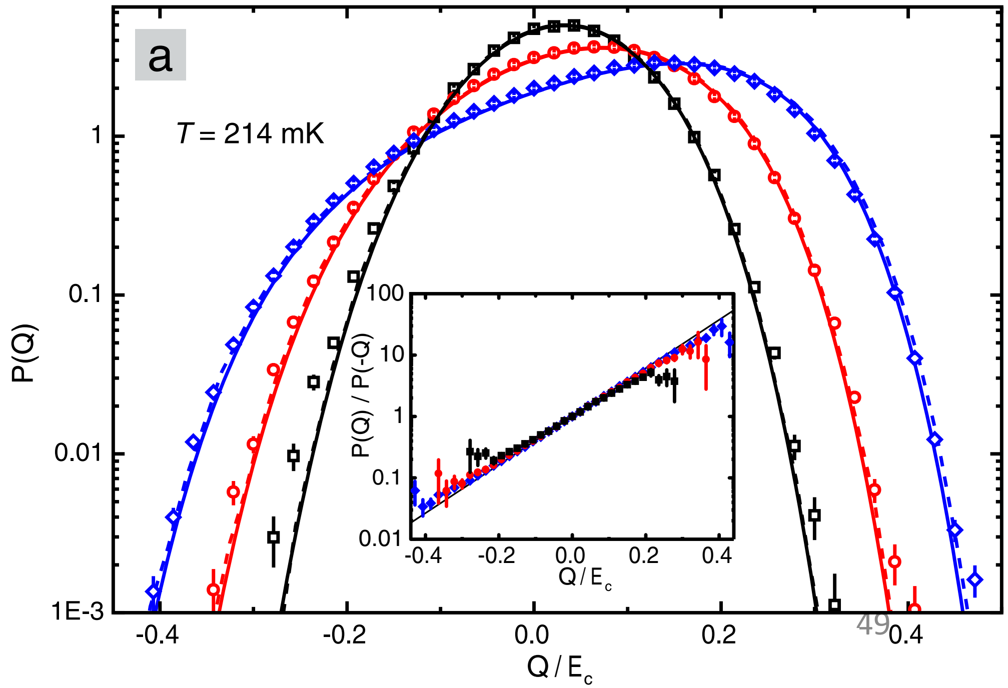


Test of the Jarzynski equality:

$$\langle e^{-Q/k_B T} \rangle = 1$$

and Crooks fluctuation theorem:

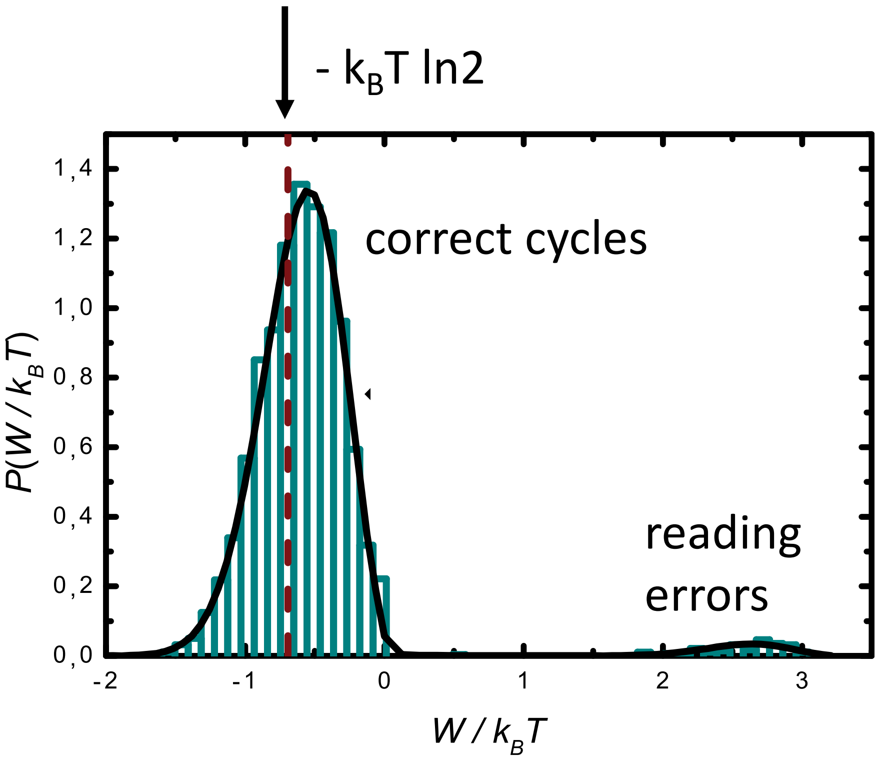
$$\frac{P_F(-Q)}{P_F(Q)} = e^{-Q/k_B T}$$

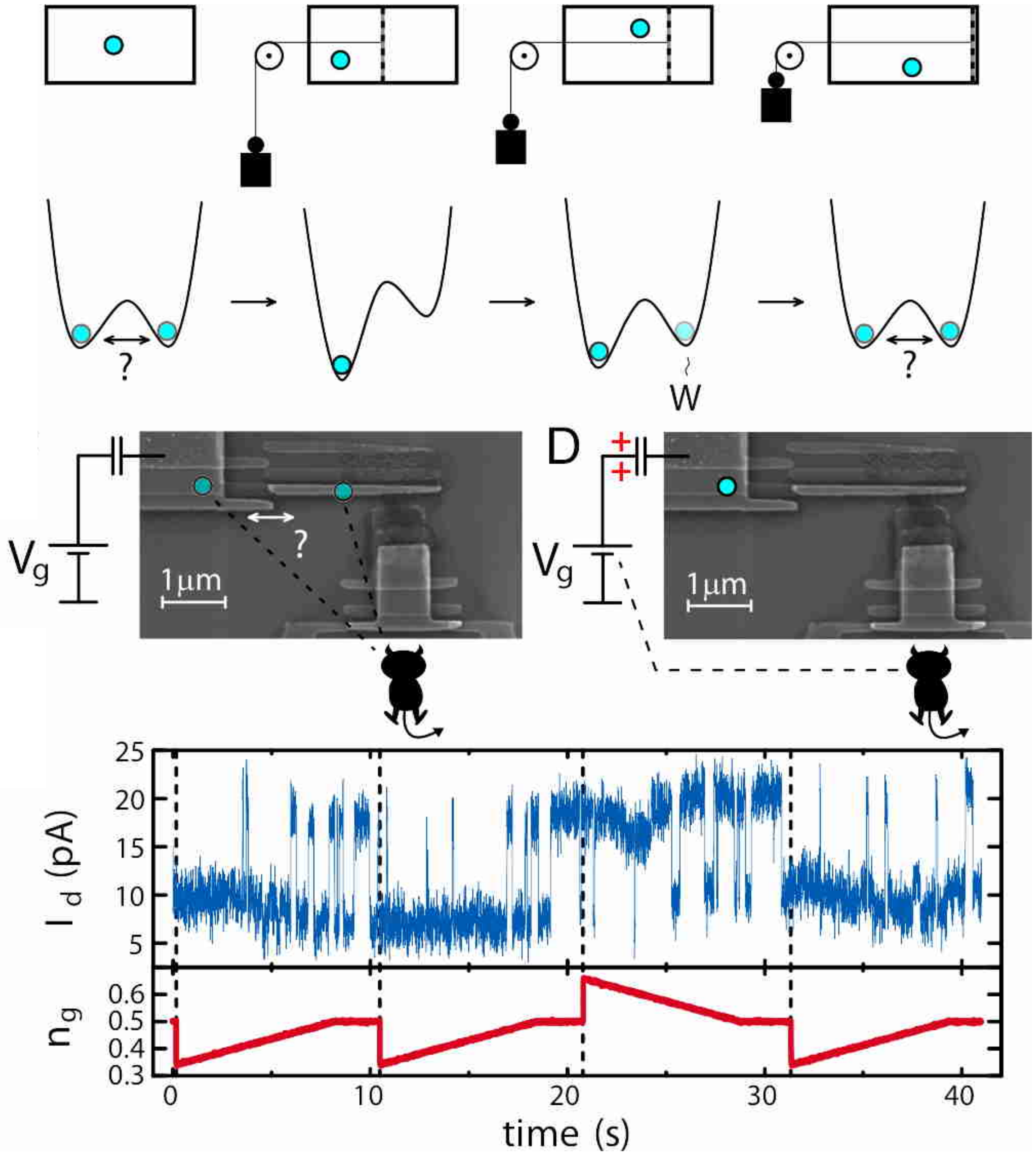


O.-P. Saira, Y. Yoon, T. Tanttu, M. Mottonen, D. V. Averin, and J. P. Pekola, PRL 109, 180601 (2012)

Demonstration of a Maxwell demon

Knowing where the particle is, $k_B T \ln 2$ of work can be extracted



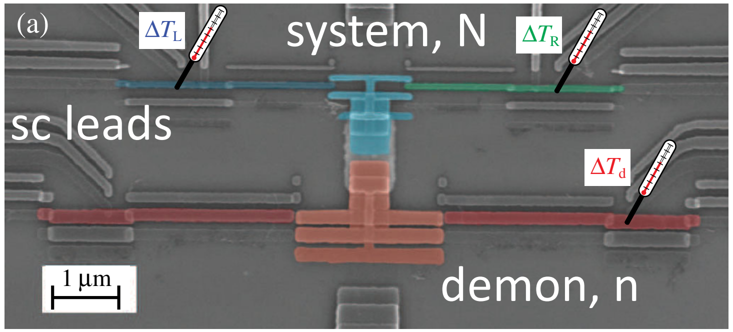


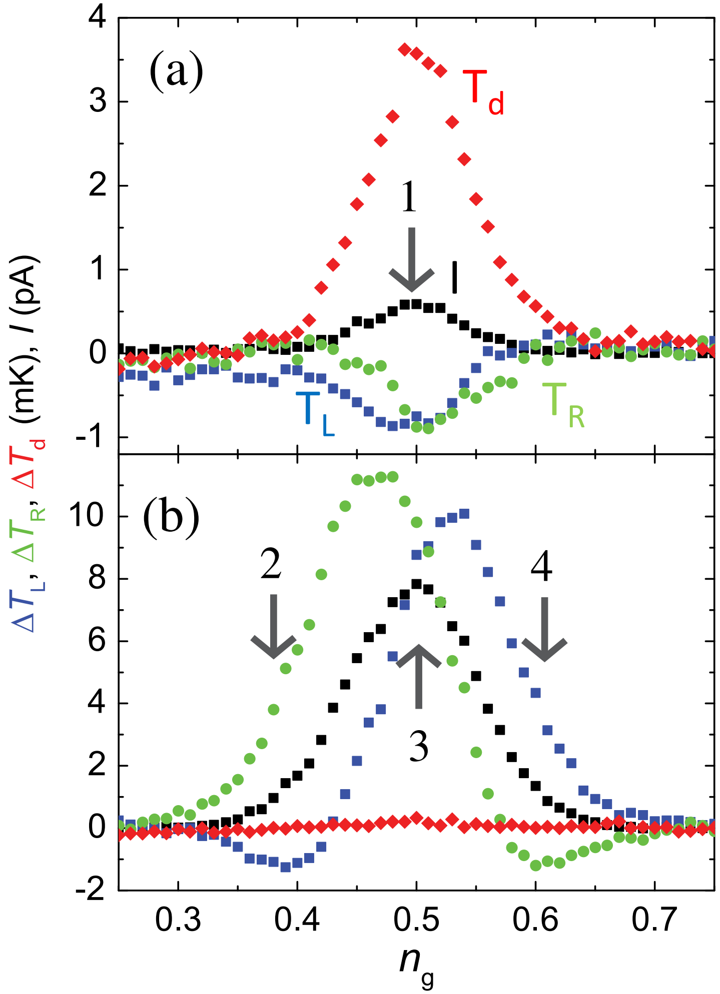
J. V. Koski, V. F. Maisi, J. P. Pekola, and D. V. Averin, PNAS 111, 13787 (2014).

An information-powered refrigerator

System SET under electrostatic influence of the unbiased demon SET

e- going into / out of the system island trapped / expelled by the demon feedback





N_g = 0.5
Maximum interaction
Maxwell demon

N_g = 0
No interaction
SET refrigeration

J. V. Koski, A. Kutvonen, I. M. Khaymovich, T. Ala-Nissila, and J. P. Pekola, PRL 115, 260602 (2015)

Thanks and happy birthday to Jukka!