Center for Quantum Devices

Danmarks Grundforskningsfond
Danish National Research Foundation

Niels Bohr Institutet

UNIVERSITY OF COPENHAGEN

XIX Meeting of Physics - Lima, Peru, 24 September 2020

Low-temperature quantum transport in semiconductor/superconductor devices

Juan Carlos Estrada Saldaña

Previously at:

DE LA RECHERCHE À L'INDUSTRIE cea

UNIVERSIDAD NACIONAL DE TRUJILLO UNT

UNIVERSITÉ DE LYON

SpinScreen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 832645

The Niels Bohr Institute

1. Condensed Matter

Center for Quantum Devices

2. Climate and Earth

Centre for ICE and CLIMATE

3. Quantum optics

iqClock

QIA QUANTUM INTERNET ALLIANCE

4. Particle physics

ICECUBE

5. Astrophysics, Cosmology

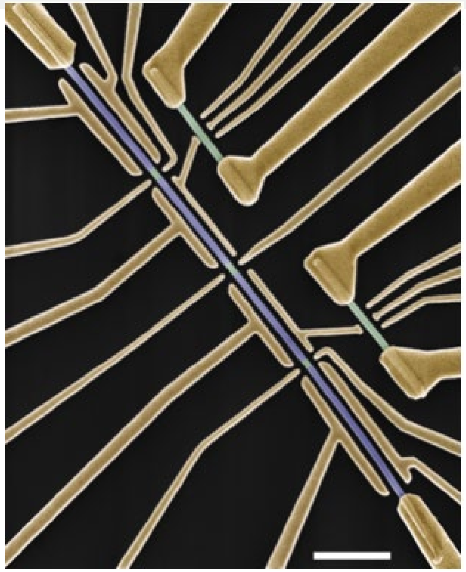
DARK

DAWN COSMIC DAWN CENTER

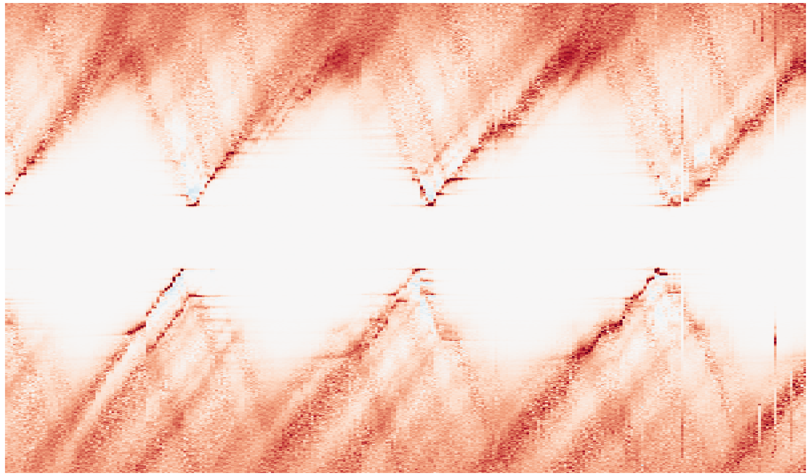
6. Biocomplexity

Center for models of life

Experimental biophysics



2. Device fabrication



1. Materials Science

Center for
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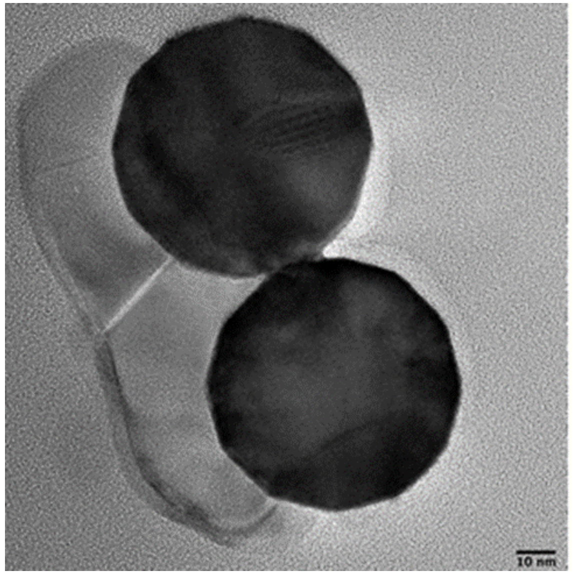
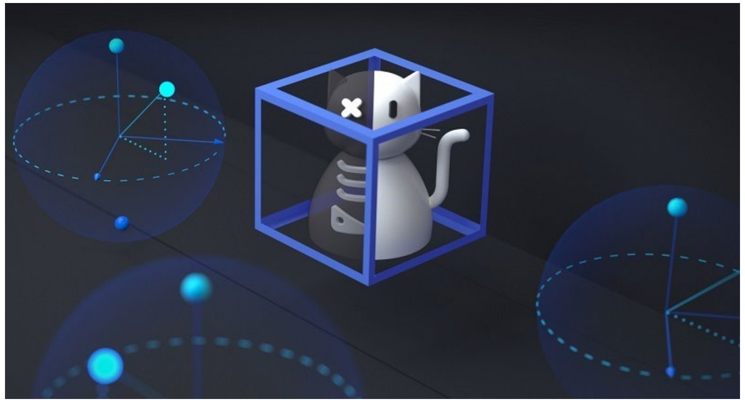
~160 people

3. Quantum transport



4. Condensed Matter Theory



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TOPOLOGICAL MATTER

Flux-induced topological superconductivity in full-shell nanowires

S. Vaitiekėnas, G. W. Wi
P. Krogstrup, R. M. Lut

TOPOLOGICAL MATTER

Majorana bound state in a coupled quantum-dot hybrid-nanowire system

M. T. Deng,[1,2] S. Vaitiekėnas,[1,3] E. B. Hansen,[1] J. Danon,[1,4] M. Leijnse,[1,5] K. Flensberg,[1] J. Nygård,[1] P. Krogstrup,[1] C. M. Marcus[1]*

LETTER

doi:10.1038/nature17162

Exponential protection of zero modes in Majorana islands

S. M. Albrecht[1]*, A. P. Higginbo

nature physics LETTERS
https://doi.org/10.1038/s41567-020-1017-3
Check for updates

Zero-bias peaks at zero magnetic field in ferromagnetic hybrid nanowires

S. Vaitiekėnas[1,2], Y. Liu[1,3], P. Krogstrup[1,3] and C. M. Marcus[1,2]

Microsoft gambles on a quantum leap in computing

Rory Cellan-Jones

Latest Issues SCIENTIFIC AMERICAN 175 Cart 0 Sign In
SHAR

Inside Microsoft's Quest for a Topological Quantum Computer

Alex Bocharov explains why the company is hoping to build qubits out of particles that some scientists think might not even exist

COMPUTERWORLD UNITED STATES

Home > Cloud Computing

FEATURE

Inside the Quantum Race: Microsoft

Who are the technology companies leading the way when it comes to enterprise quantum computing research? We start this series with the Redmond-based vendor Microsoft

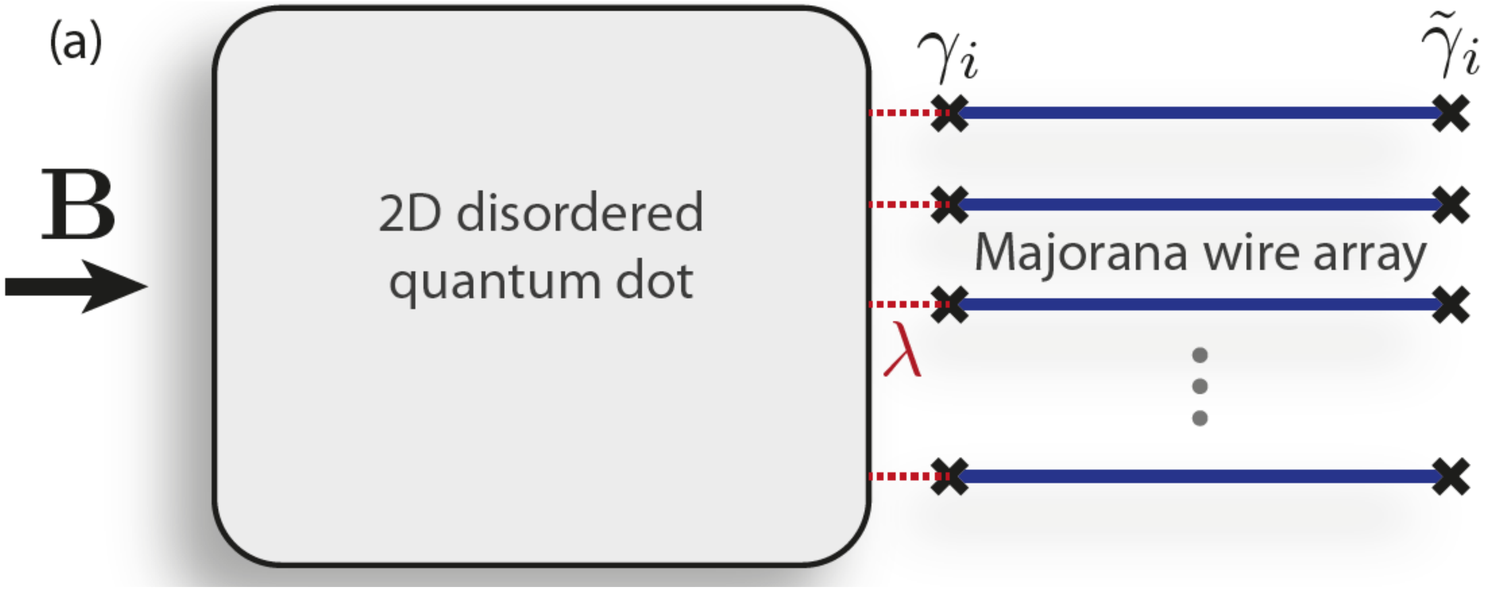
PHYSICAL REVIEW X **7**, 031006 (2017)

Black Hole on a Chip: Proposal for a Physical Realization of the Sachdev-Ye-Kitaev model in a Solid-State System

D. I. Pikulin[1] and M. Franz[2]

Approximating the Sachdev-Ye-Kitaev model with Majorana wires

Aaron Chew,[1] Andrew Essin,[2] and Jason Alicea[1,3]



Fortschritte der Physik
Progress of Physics

Fortschr. Phys. **65**, No. 5, 1700034 (2017) / DOI 10.1002/prop.201700034

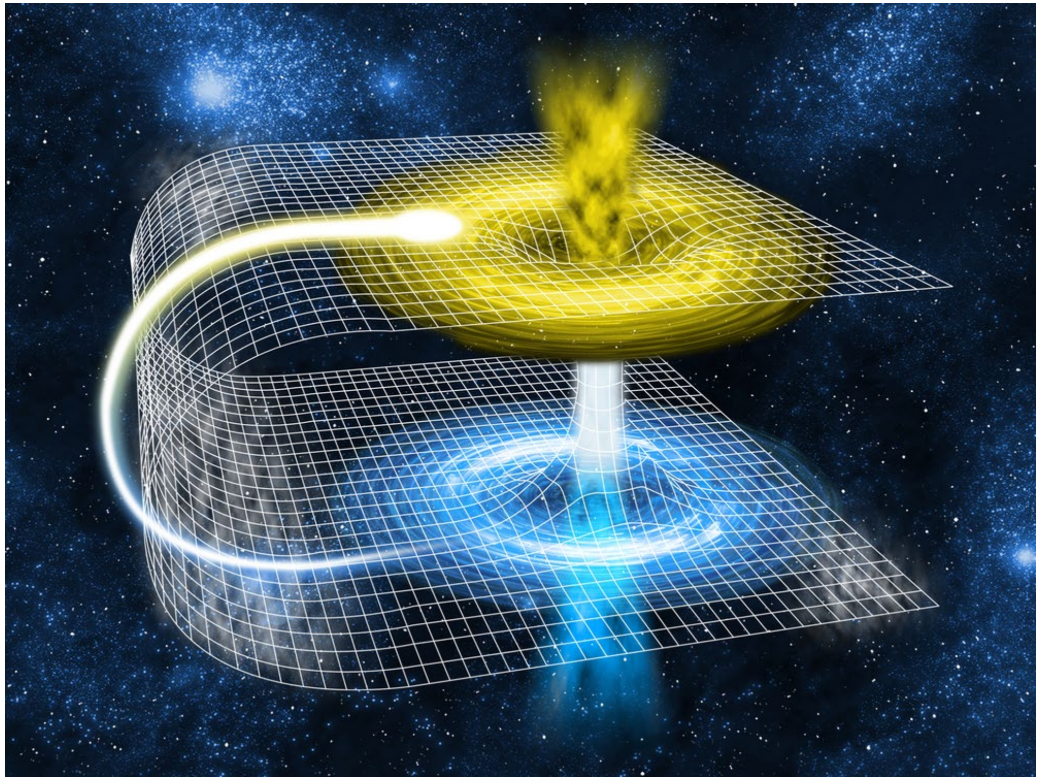
Diving into traversable wormholes

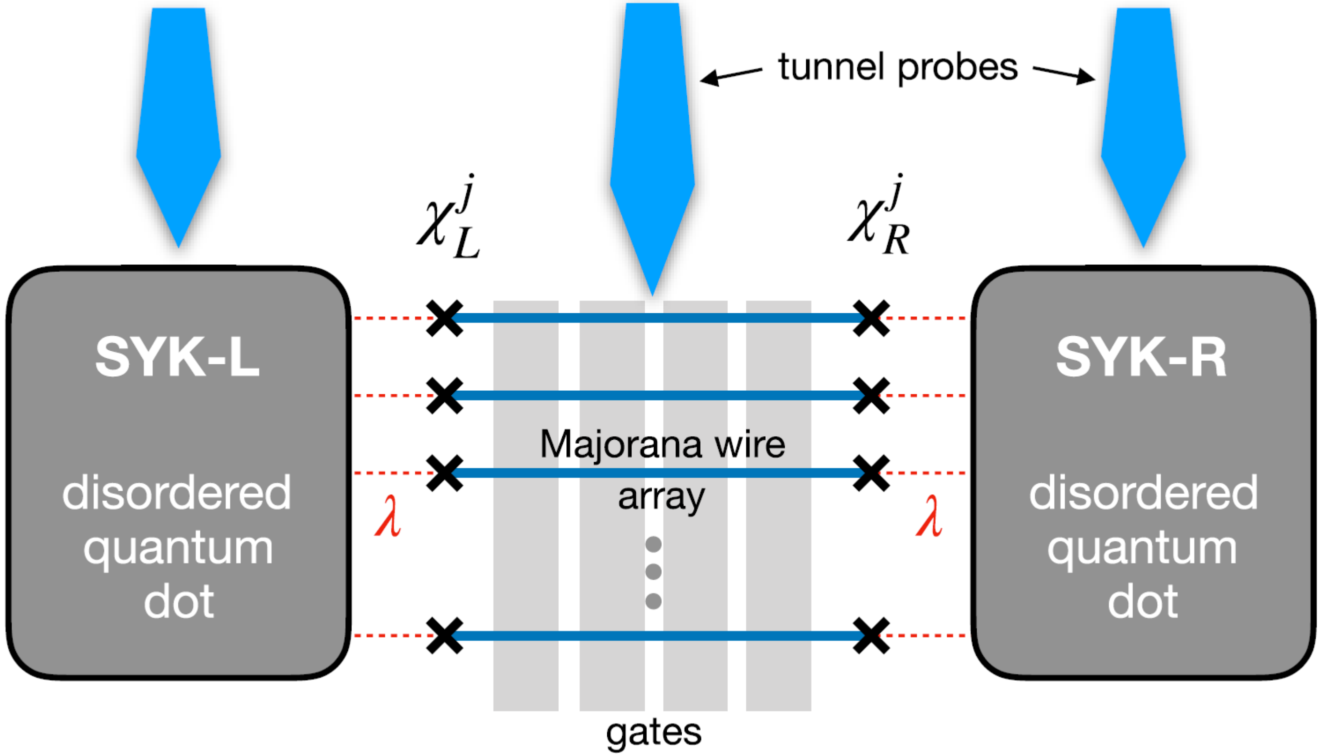
Juan Maldacena[1,], Douglas Stanford[1], and Zhenbin Yang[2]*

PHYSICAL REVIEW RESEARCH **2**, 013254 (2020)

Diagnosing quantum chaos in many-body systems using entanglement as a resource

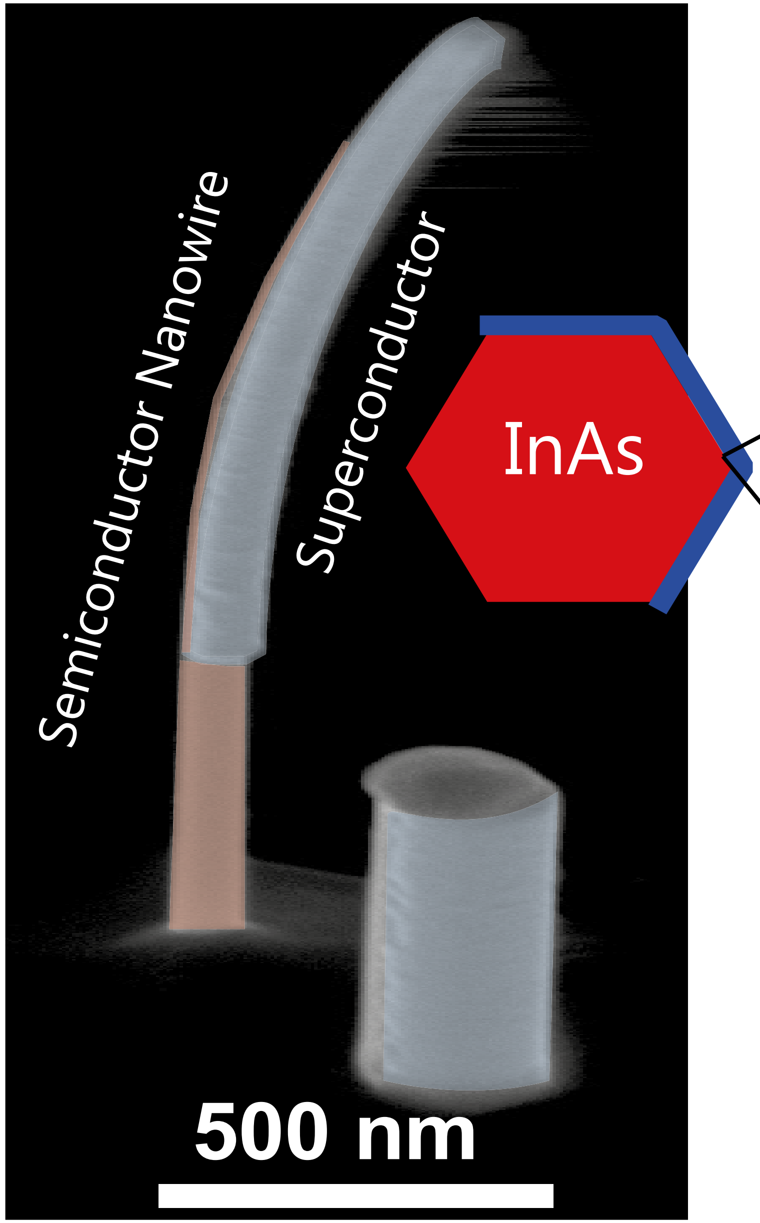
Étienne Lantagne-Hurtubise,[1,2,*] Stephan Plugge,[1,†] Oguzhan Can,[1] and Marcel Franz[1,2]



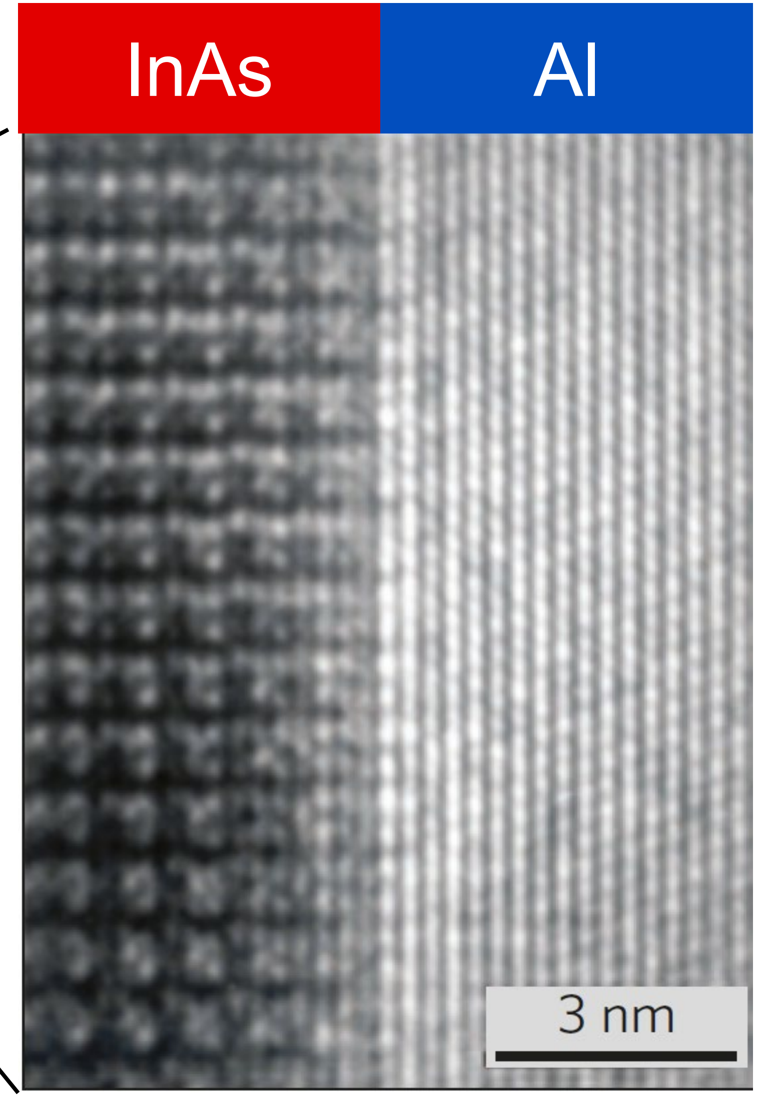


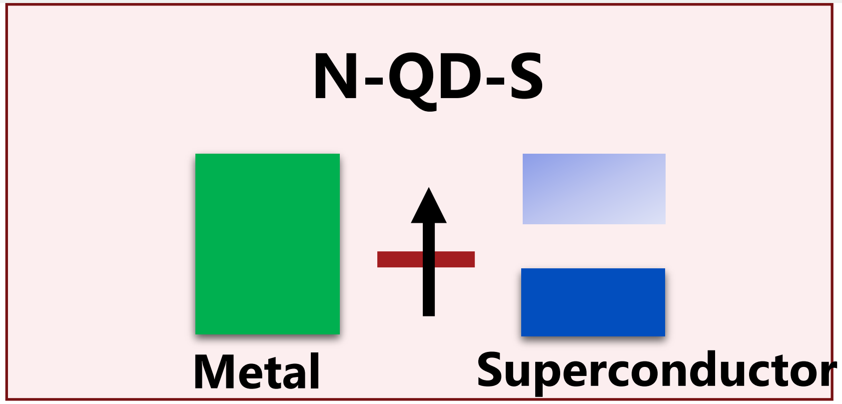
Today, I'll talk about how we use these nanowires in our group

Nanowire

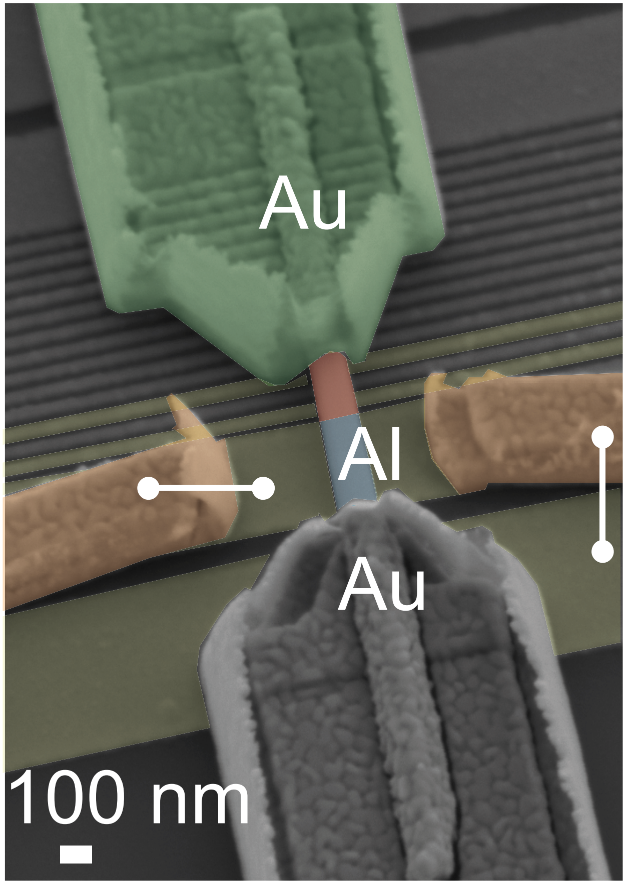


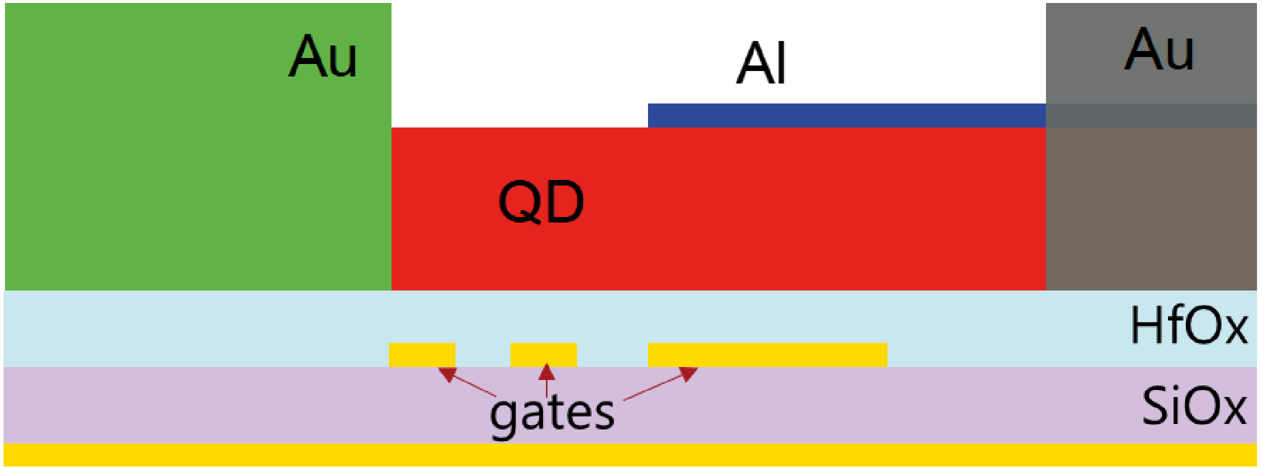
Semiconductor-Superconductor interface





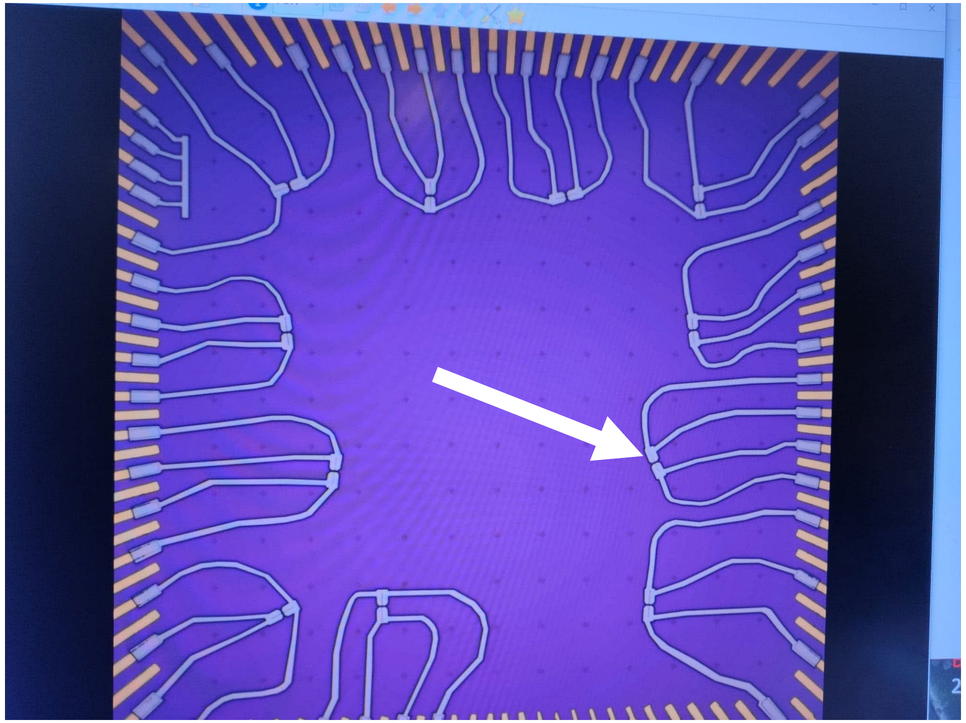
Device



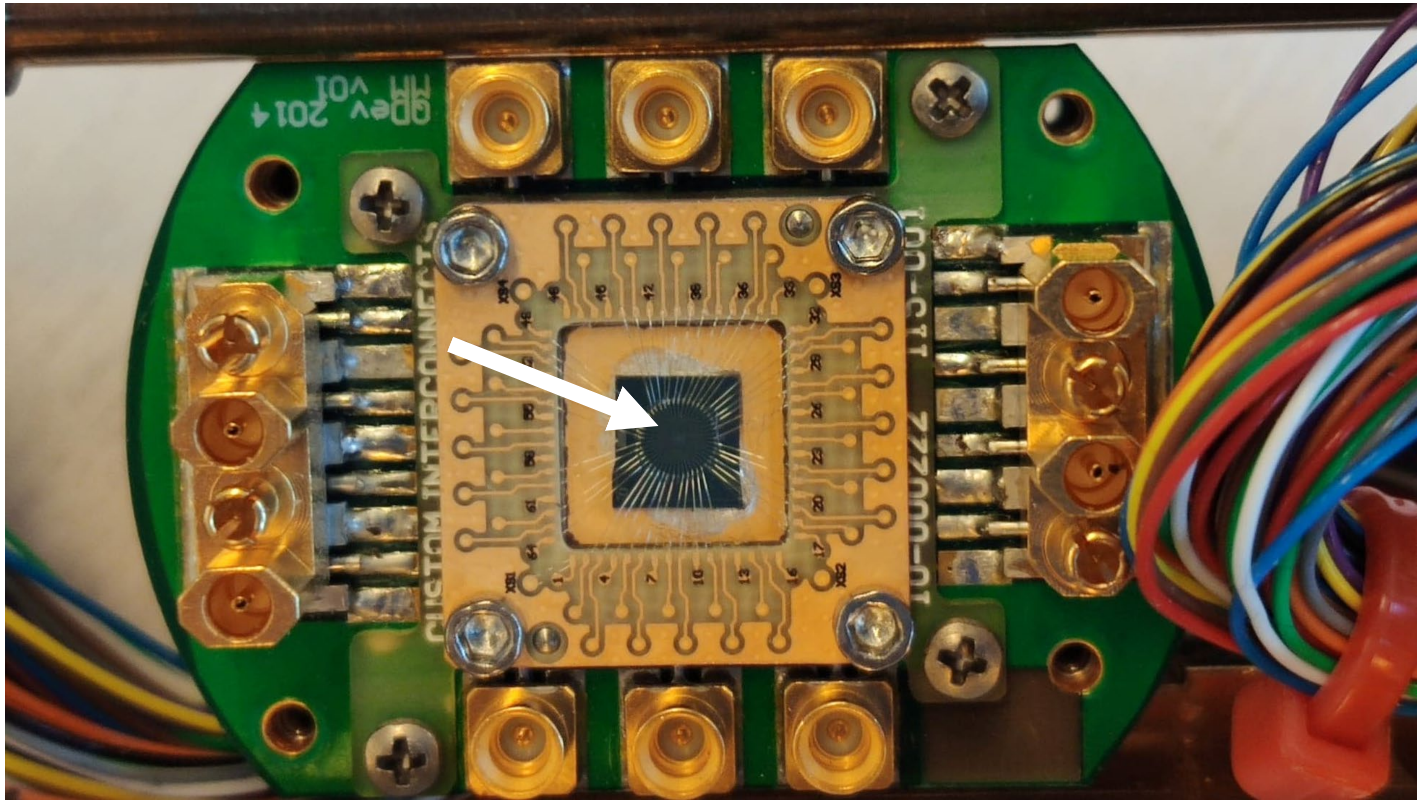


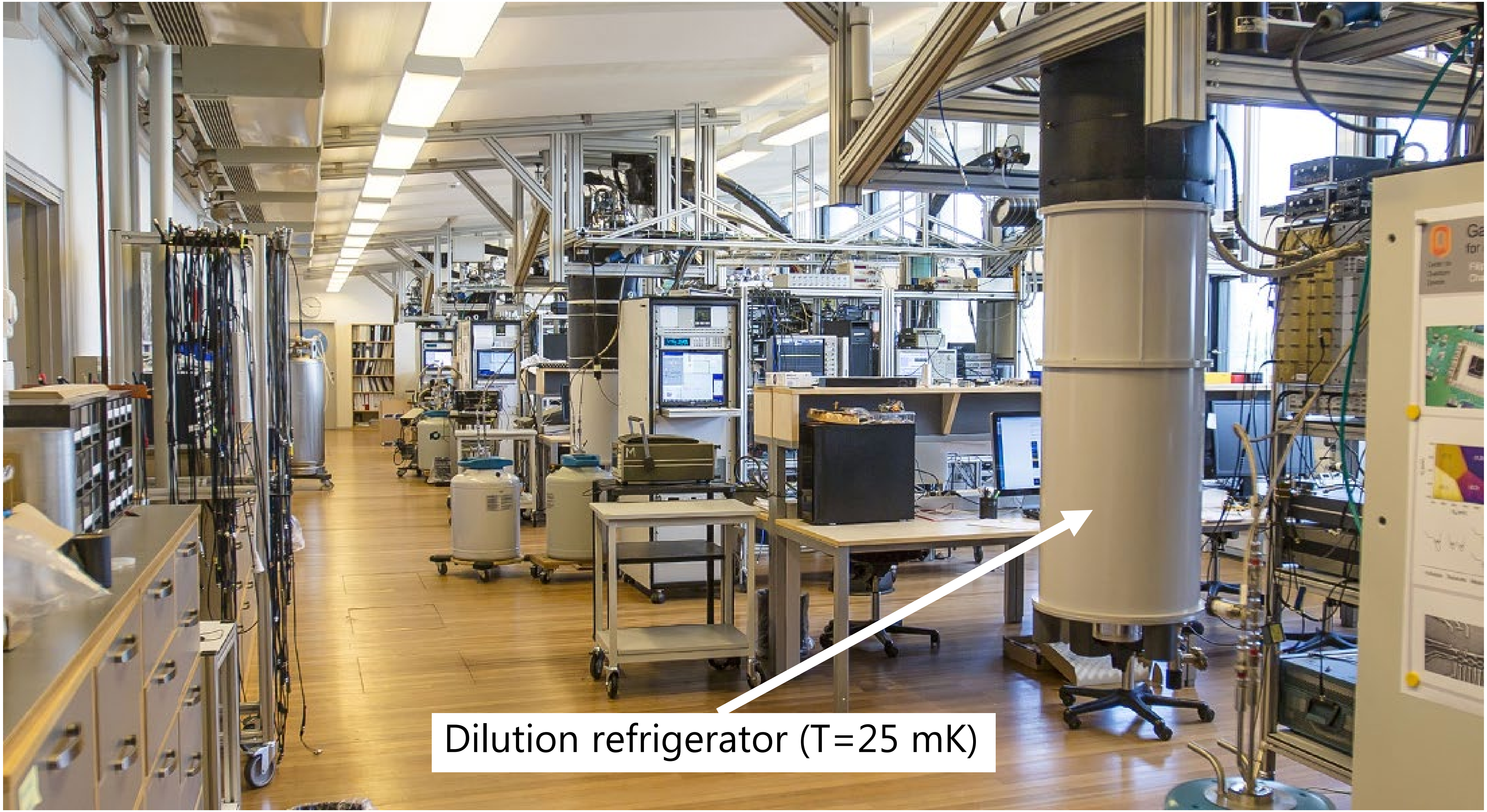
Estrada Saldaña,..., Nygård, Communications Physics, 2020

Devices

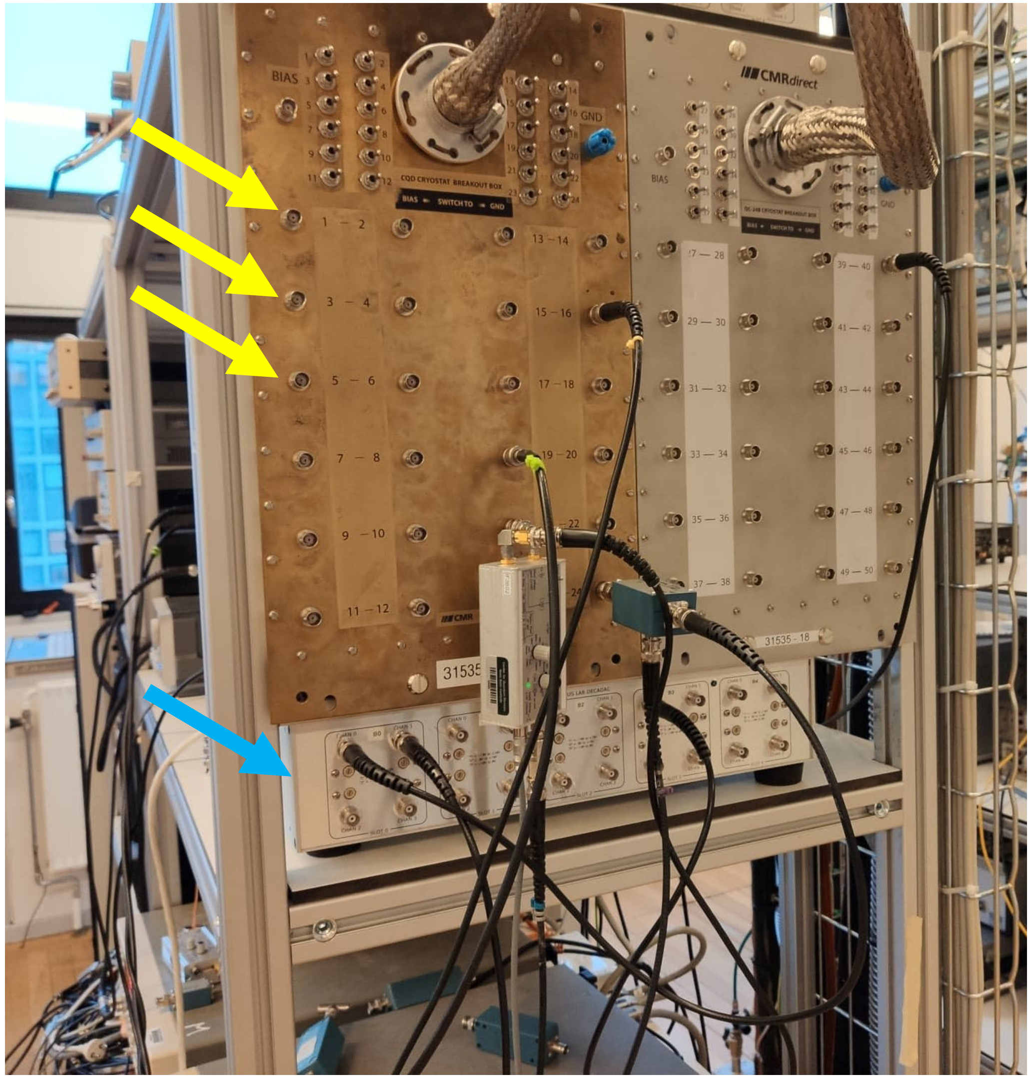


Sample on chip carrier

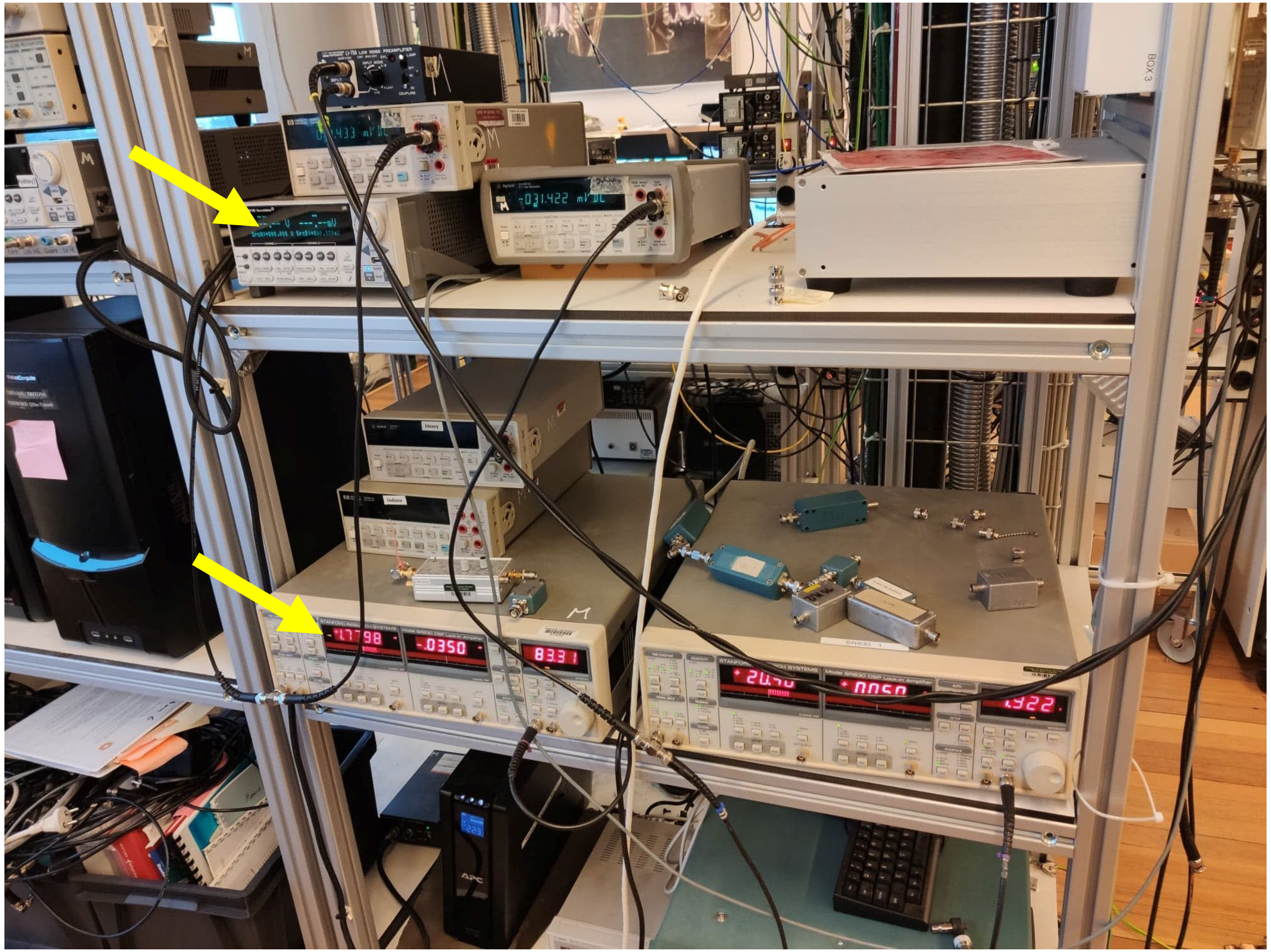



Dilution refrigerator (T=25 mK)

Access to devices

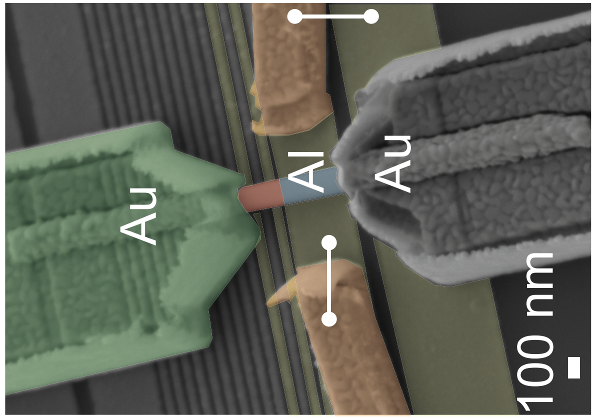


Digital multimeters and lock-in amplifiers

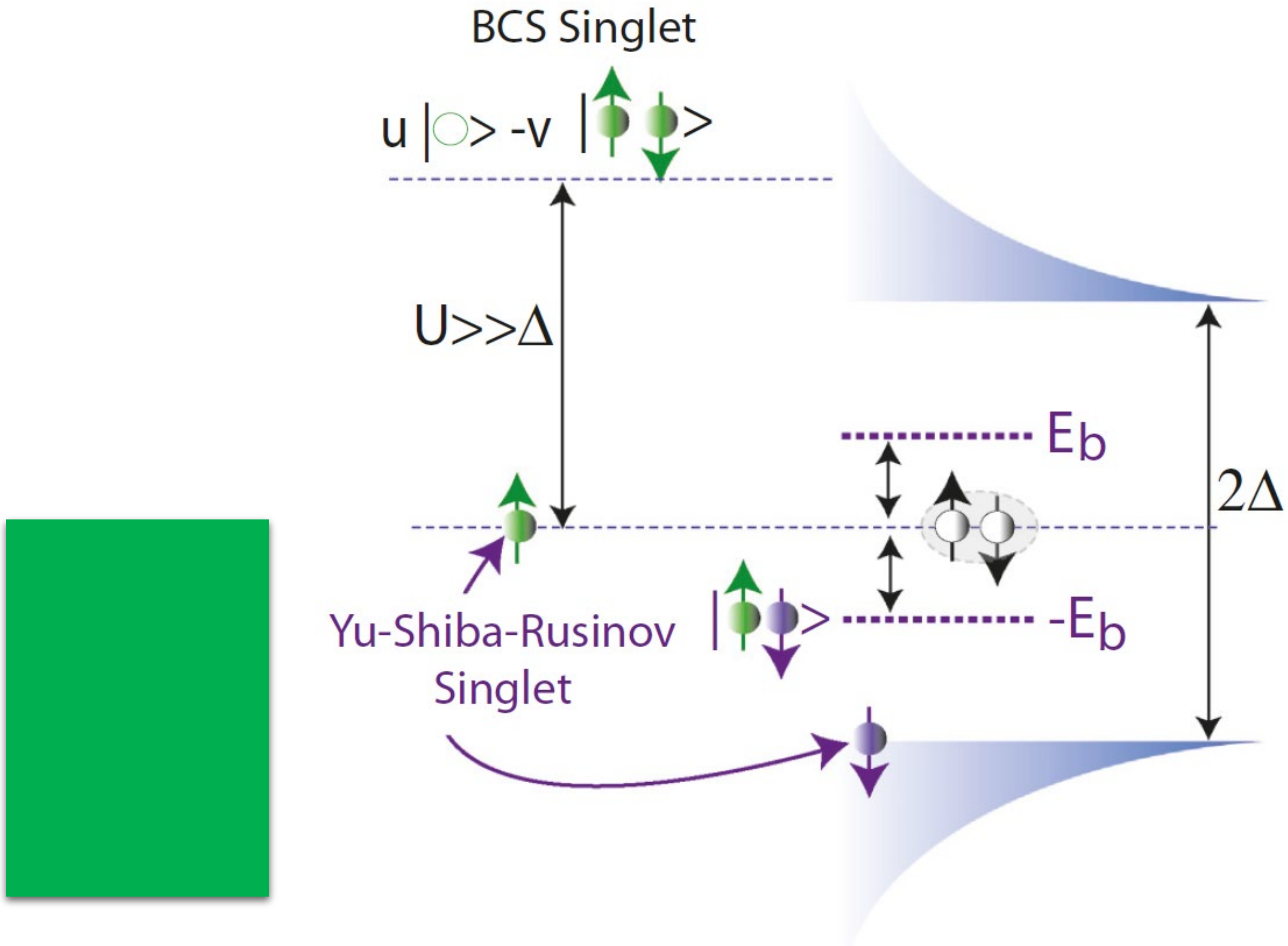


Metal Quantum dot Superconductor

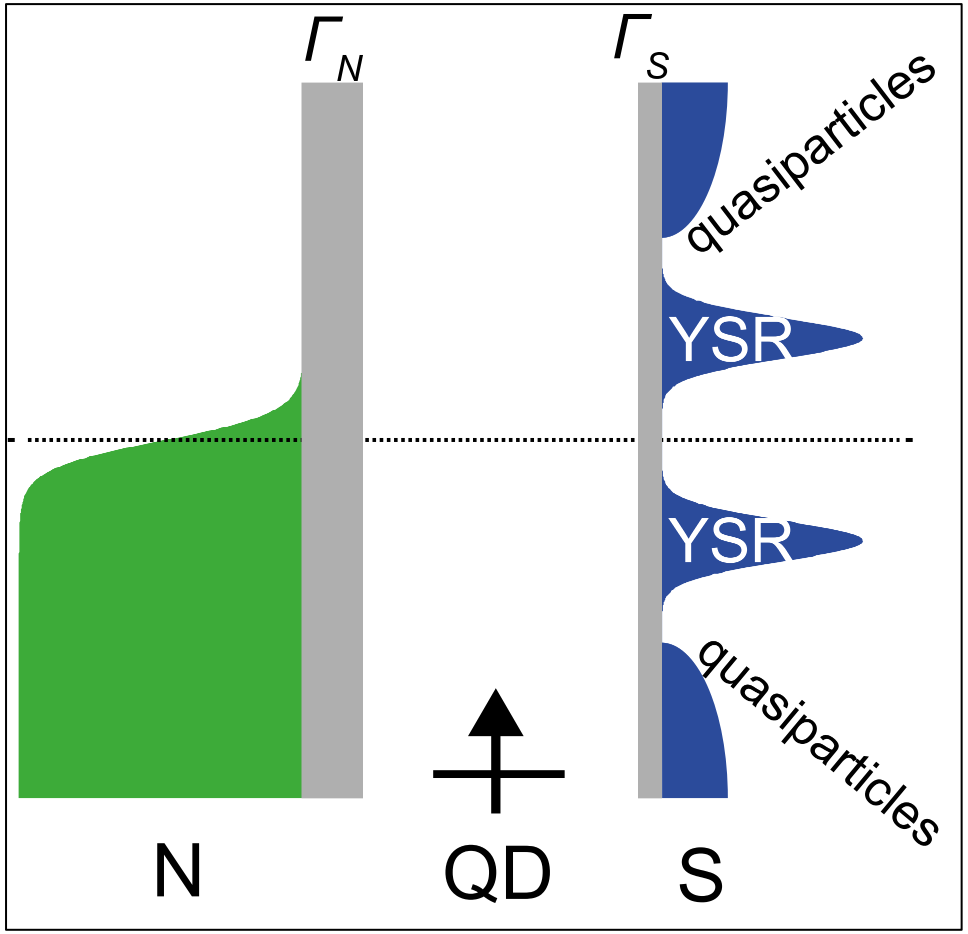
Device



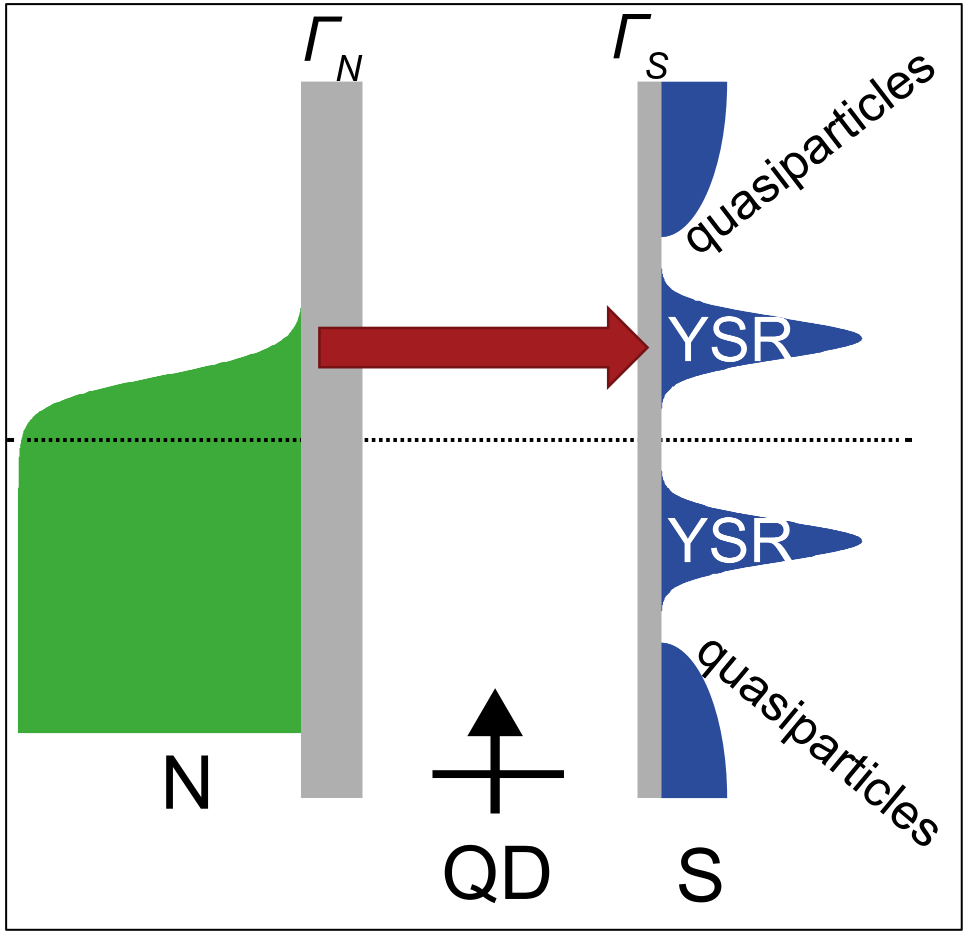
Model



Voltage: No
Conductance: No

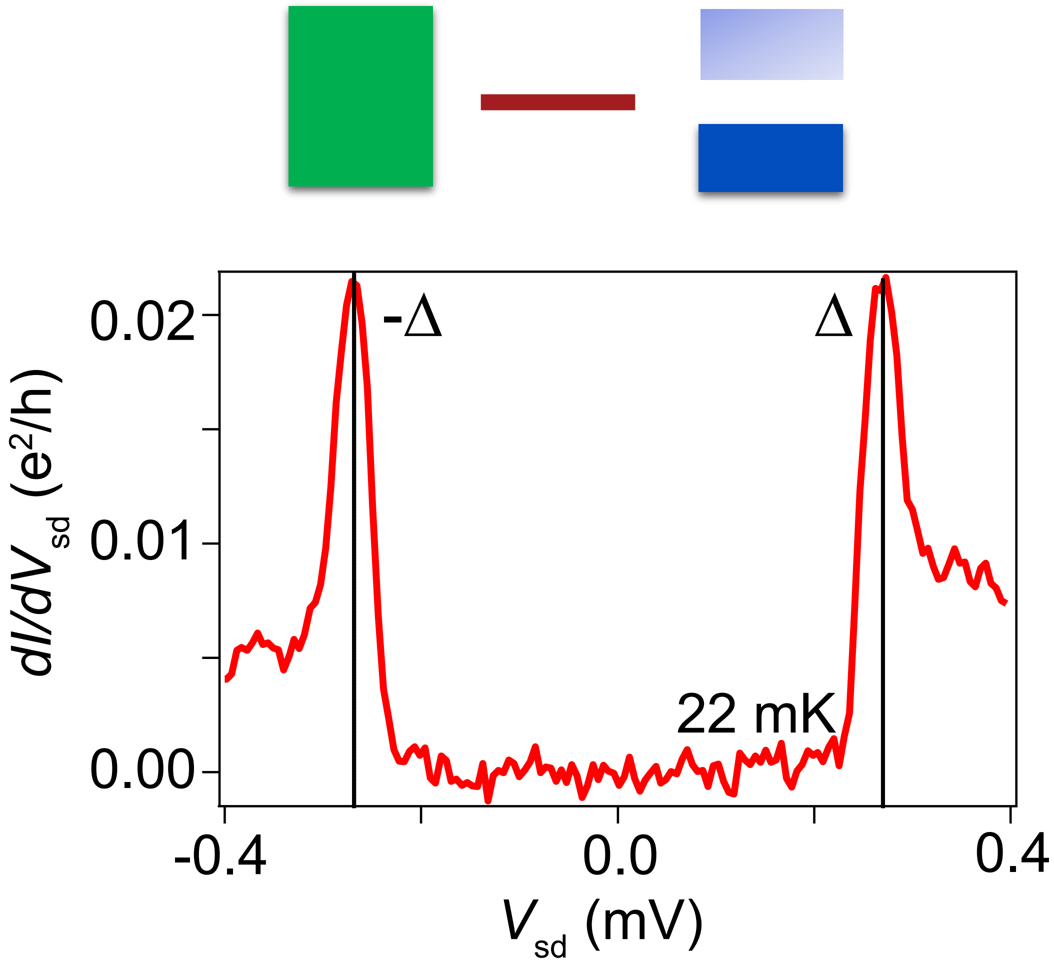


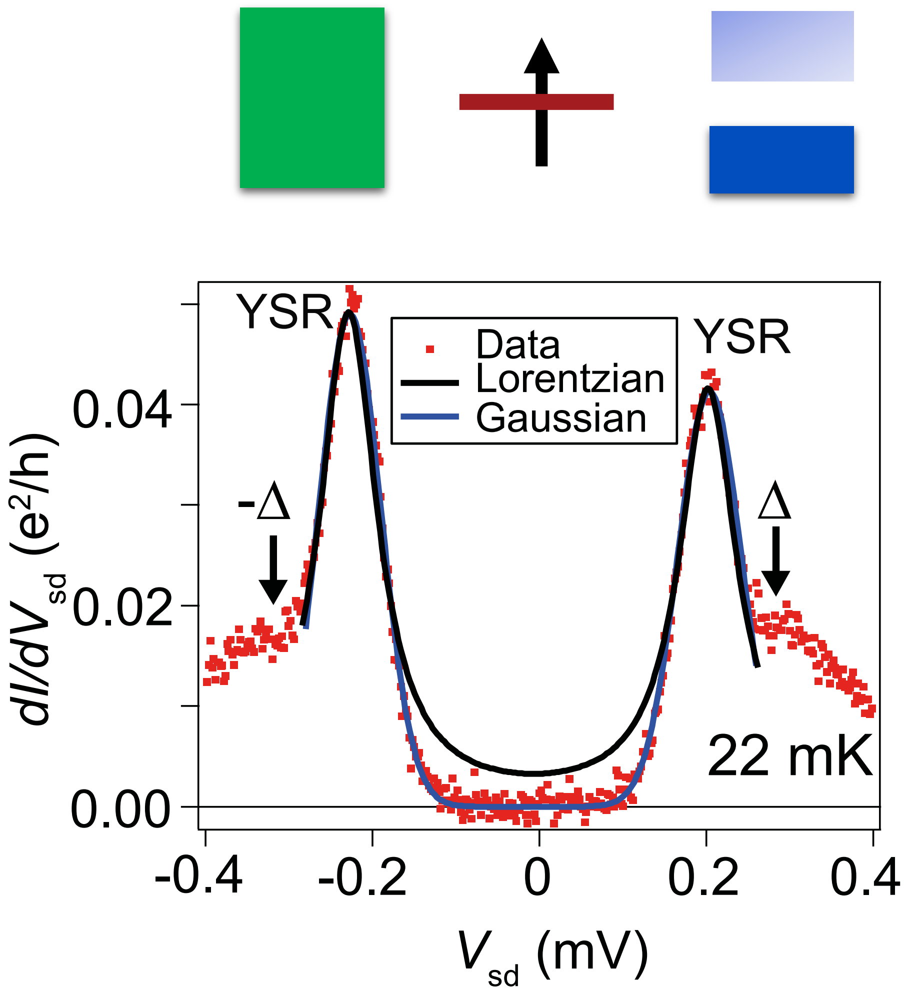
Voltage: Yes
Conductance: Yes



YSR: Yu-Shiba-Rusinov

With and without a spin





Estrada Saldaña,..., Nygård, Communications Physics, 2020

A different way of probing YSR states

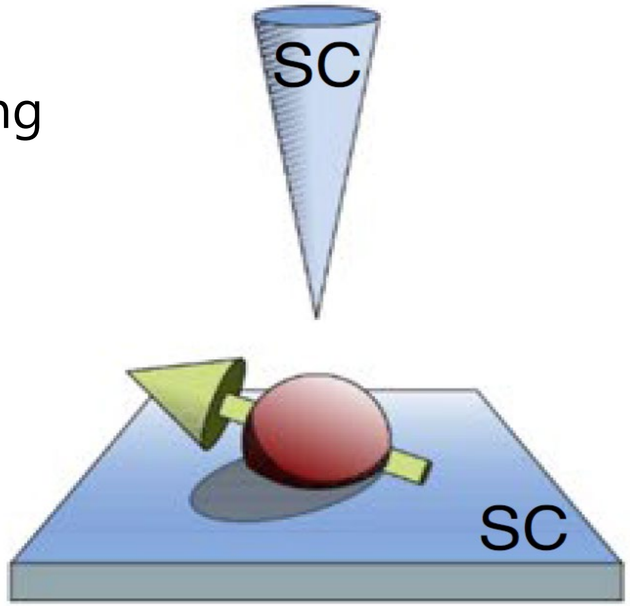
Pros:
- Spatial dependence

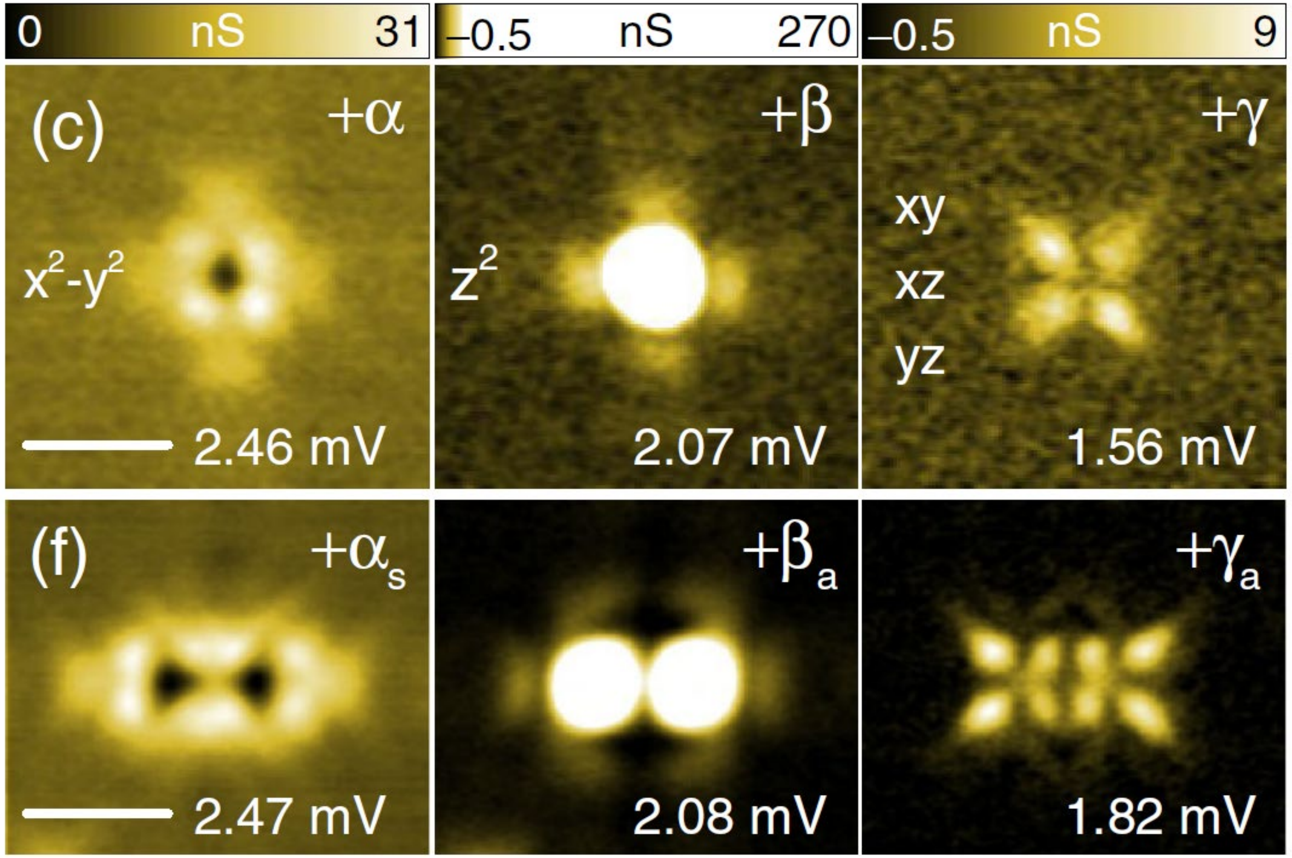
Cons:
- Hard to tune coupling to superconductor
- Hard to tune energy level

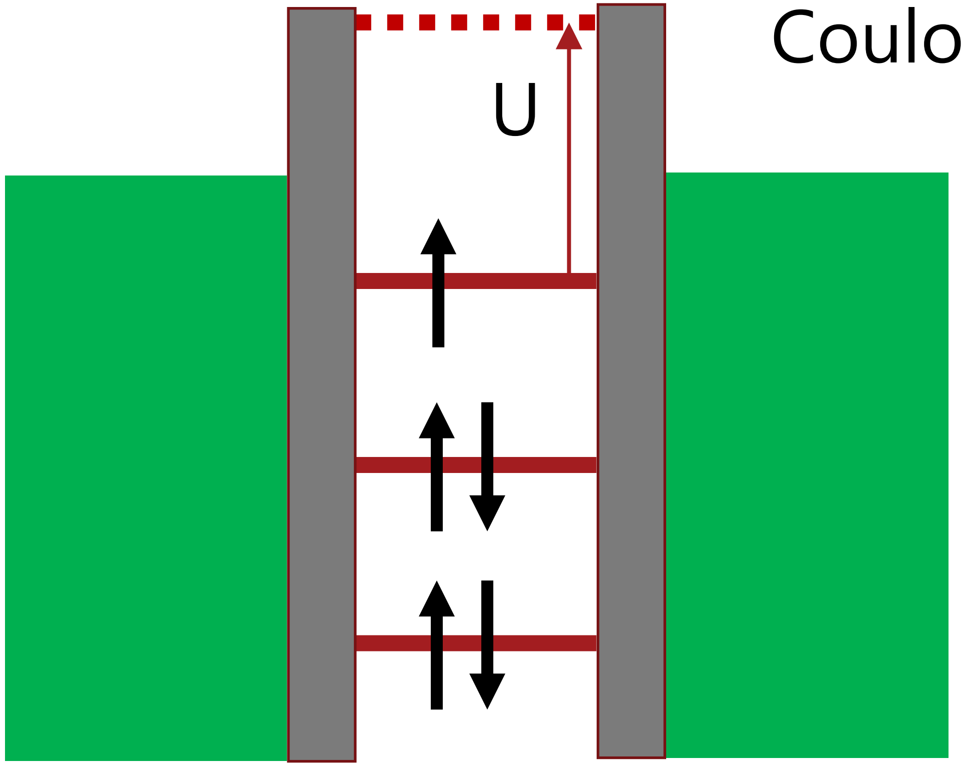
PHYSICAL REVIEW LETTERS **120,** 156803 (2018)

Wave-Function Hybridization in Yu-Shiba-Rusinov Dimers

Michael Ruby,[1] Benjamin W. Heinrich,[1] Yang Peng,[2,3,4] Felix von Oppen,[2] and Katharina J. Franke[1]

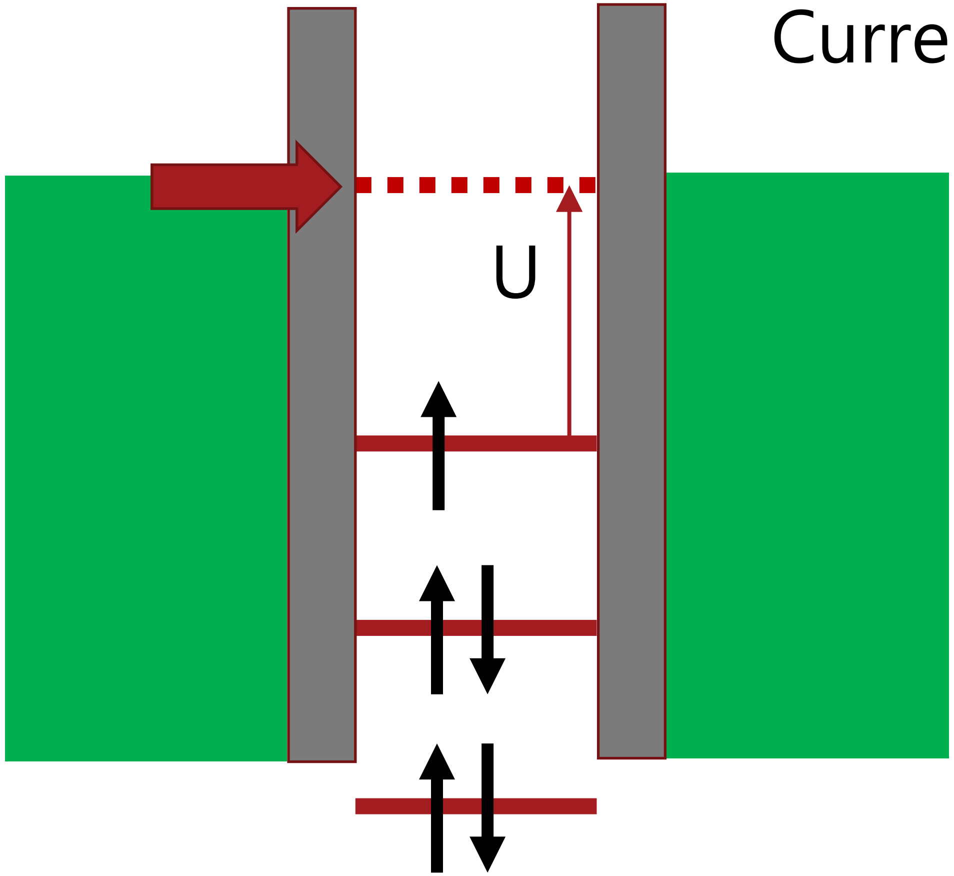






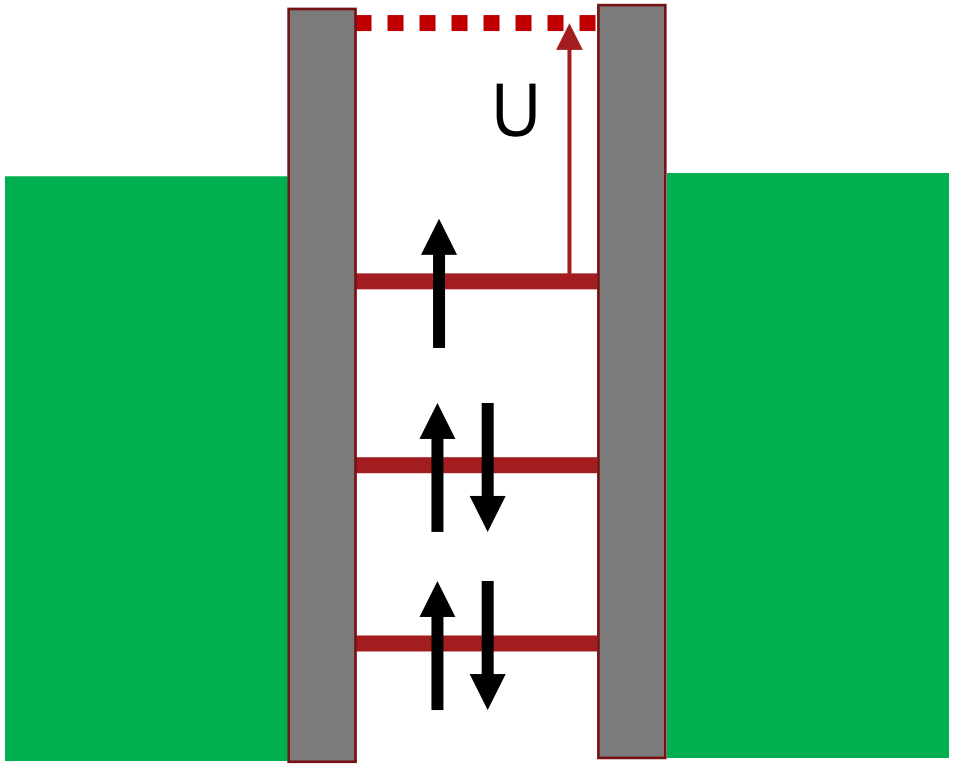
Coulomb blockade

Current can flow



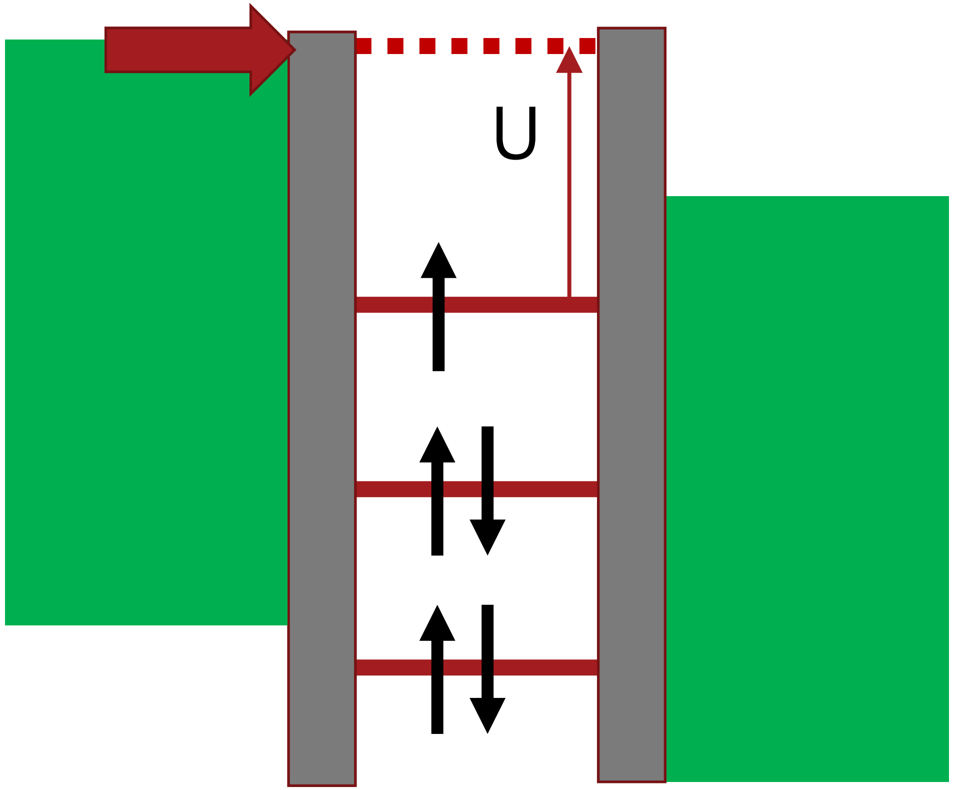
++Gate voltage

Coulomb blockade

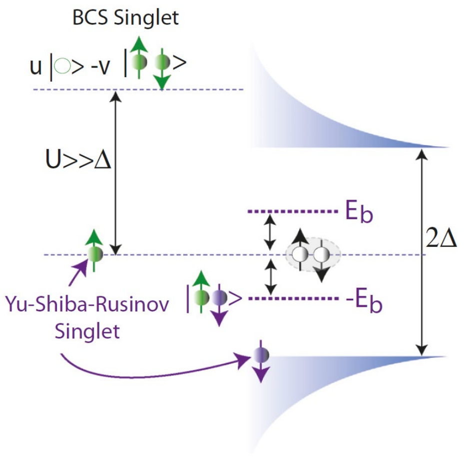


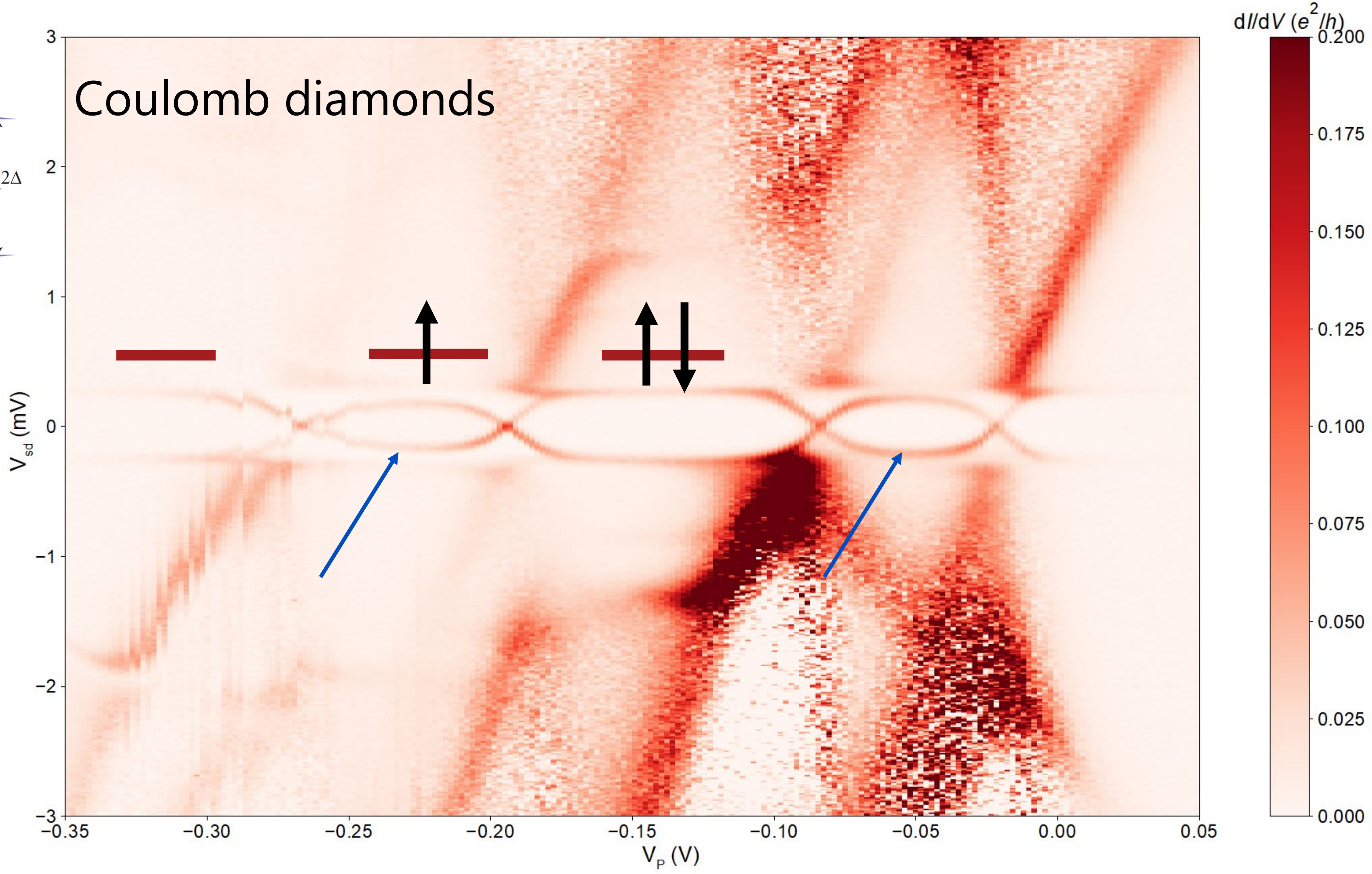
$V_{sd}=0$

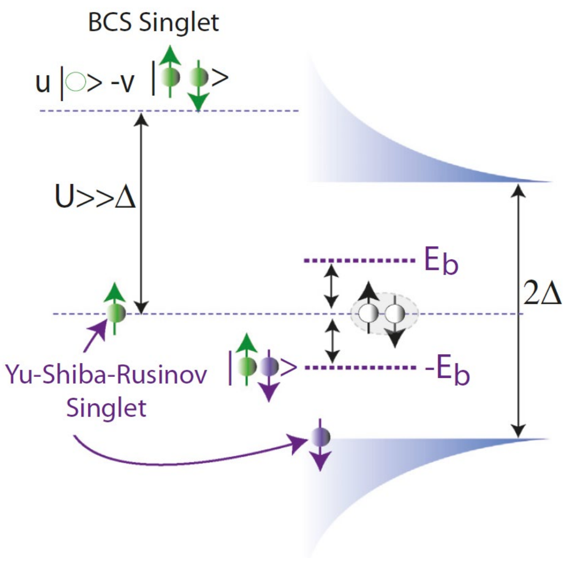
Sequential tunnelling



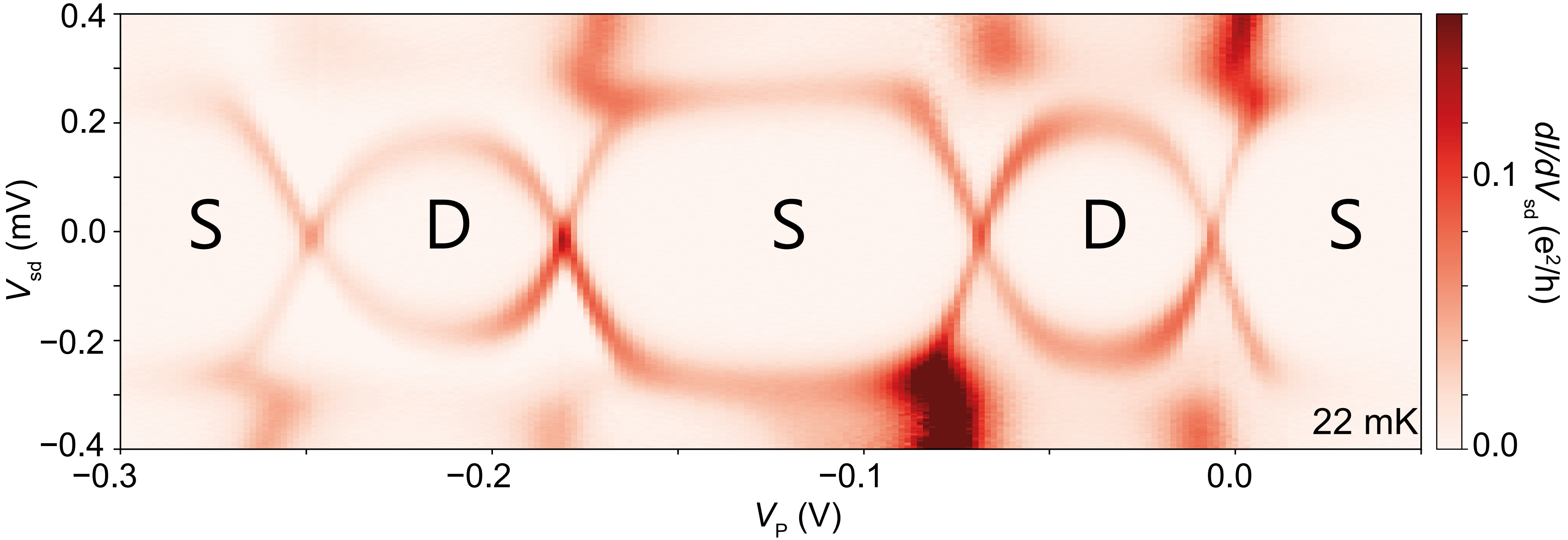
$V_{sd}>U$


BCS Singlet
u |○> -v |↑↓>
U>>Δ
Eb
2Δ
-Eb
Yu-Shiba-Rusinov
Singlet


Coulomb diamonds
V_{sd} (mV)
V_P (V)
dI/dV (e^2/h)
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000

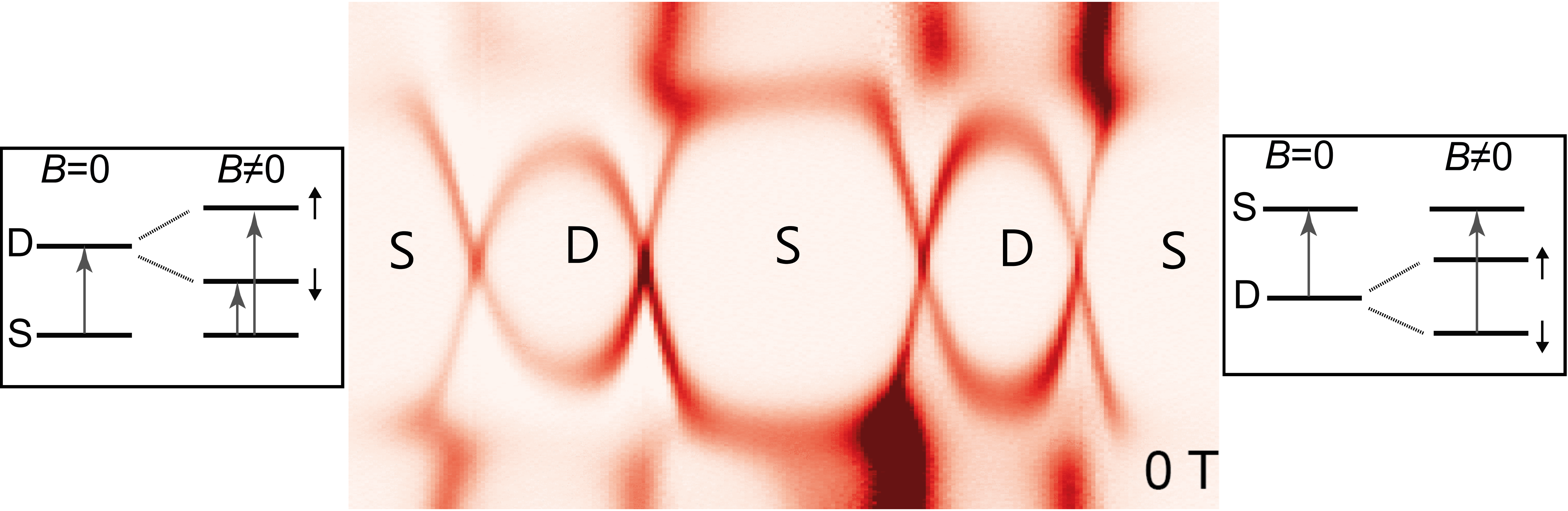


BCS Singlet
u |○> -v |↑↓>
U>>Δ
Eb
2Δ
Yu-Shiba-Rusinov
Singlet
-Eb

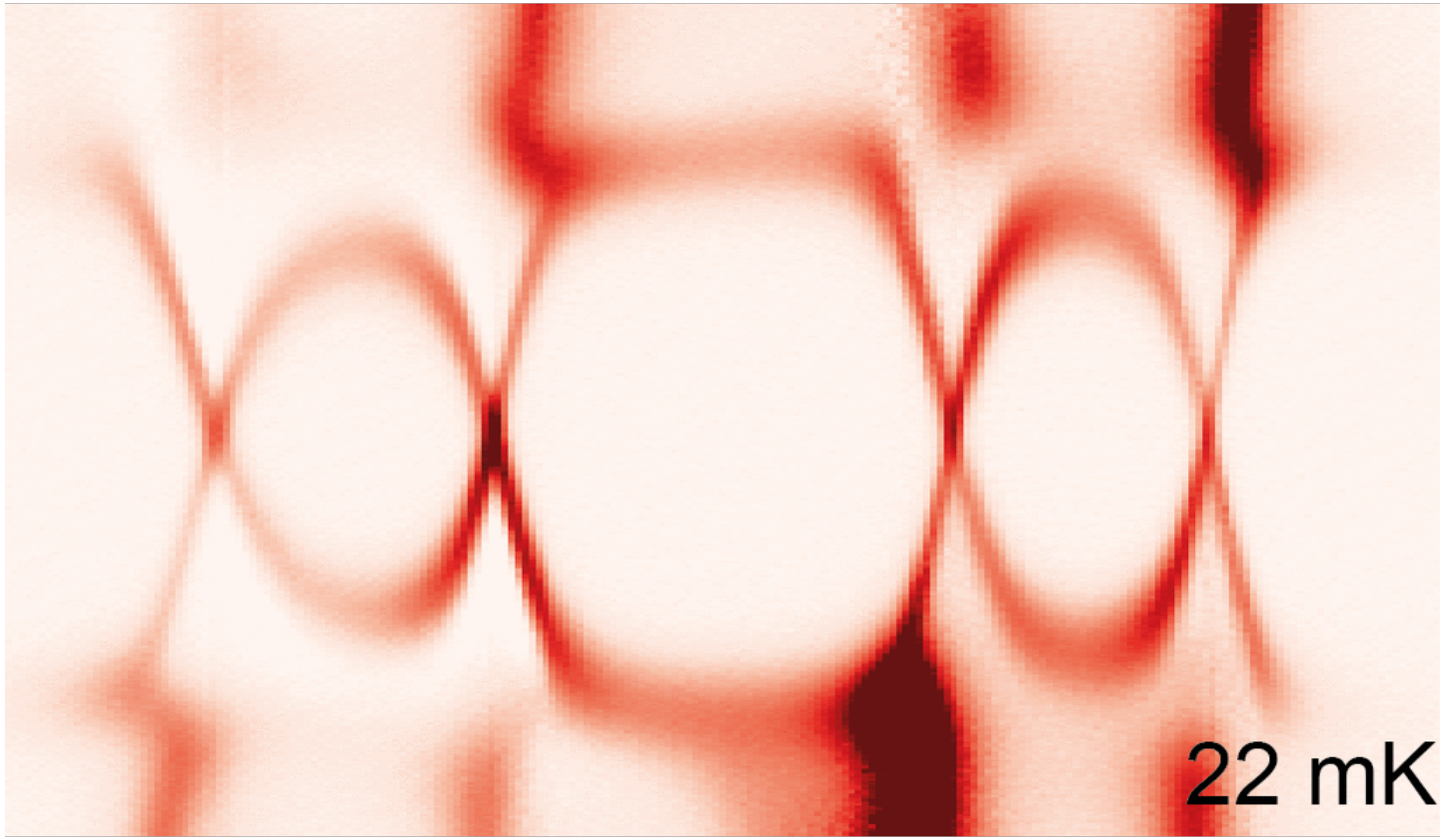


S
D
S
D
S
22 mK
Vsd (mV)
VP (V)
dI/dVsd (e2/h)
0.4
0.2
0.0
−0.2
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.0

Zeeman effect

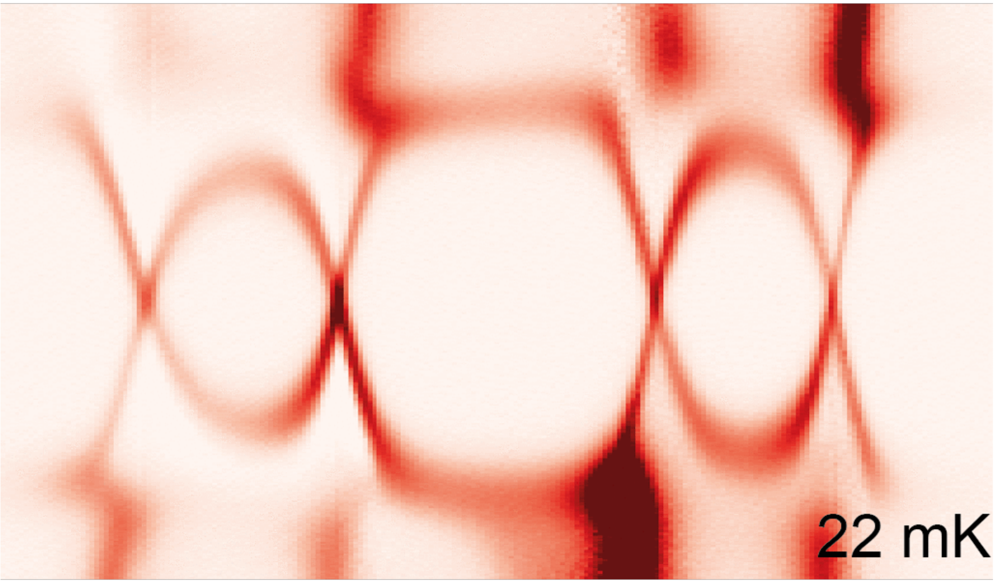


Temperature dependence



Estrada Saldaña,..., Nygård, Communications Physics, 2020

Not explained by theory (yet!)



Zitko, PRB, 2016

In Fig. 2(b) we consider the peak positions. The δ peak does not move with temperature. This is expected since its position $\omega_\delta = \epsilon$ is given by the energy difference between two discrete eigenstates of the Hamiltonian; thus it is a property of the operator itself and does not involve any thermal effects. The continuum part of the subgap spectrum is a peaked function (see Fig. 3). The position of this peak ω_{peak} almost coincides with the δ-peak position,

$$\omega_{\text{peak}} \approx \omega_\delta = \epsilon, \tag{13}$$

since the main contribution comes from processes linking the bottommost part of both continua. Interestingly, ω_{peak} is very weakly temperature dependent even at T of order Δ. We

More details at:

COMMUNICATIONS PHYSICS

ARTICLE

https://doi.org/10.1038/s42005-020-0392-5 OPEN

Check for updates

Temperature induced shifts of Yu-Shiba-Rusinov resonances in nanowire-based hybrid quantum dots

Juan Carlos Estrada Saldaña[1], Alexandros Vekris[1,2], Victoria Sosnovtseva[1], Thomas Kanne[1], Peter Krogstrup[1,3], Kasper Grove-Rasmussen[1] & Jesper Nygård[1]✉

Next degree of complexity: double quantum dots

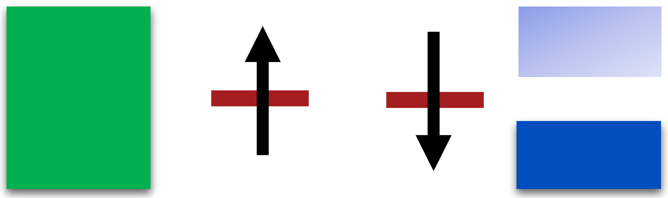
ARTICLE

DOI: 10.1038/s41467-018-04683-x OPEN

Yu–Shiba–Rusinov screening of spins in double quantum dots

K. Grove-Rasmussen[1], G. Steffensen[1], A. Jellinggaard[1], M.H. Madsen[1], R. Žitko[2,3], J. Paaske[1] & J. Nygård[1]

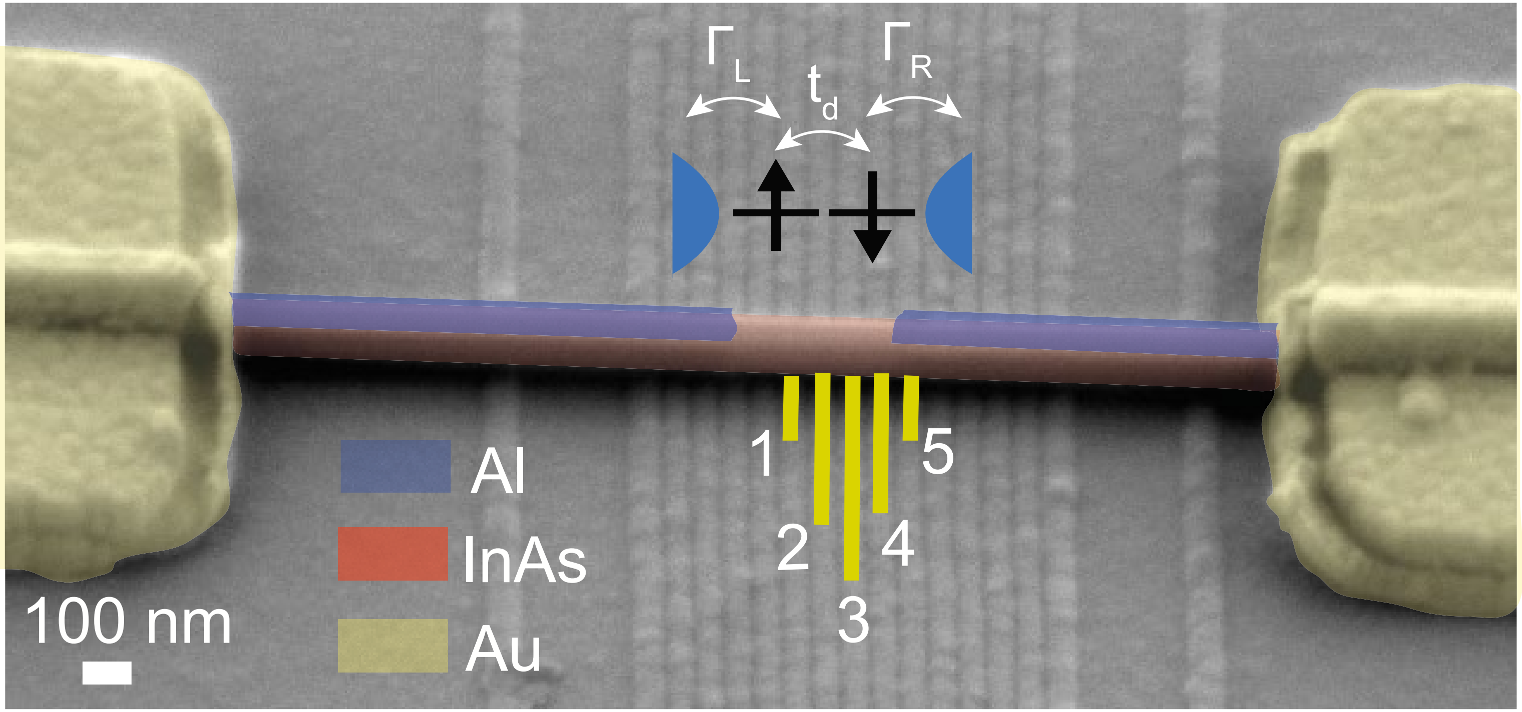
N-DQD-S

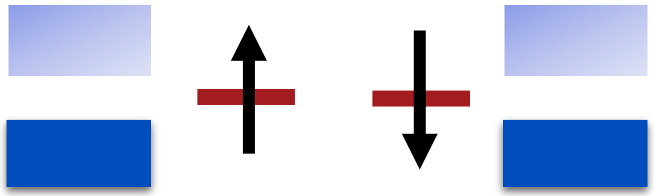


PHYSICAL REVIEW LETTERS **121**, 257701 (2018)

Supercurrent in a Double Quantum Dot

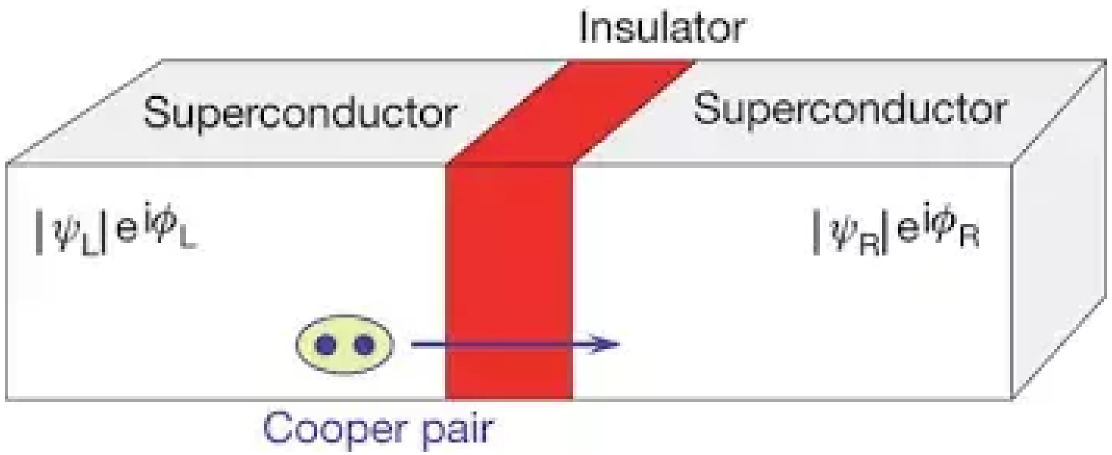
J. C. Estrada Saldaña,[1] A. Vekris,[1] G. Steffensen,[1] R. Žitko,[2,3] P. Krogstrup,[1,4] J. Paaske,[1]
K. Grove-Rasmussen,[1] and J. Nygård[1,*]

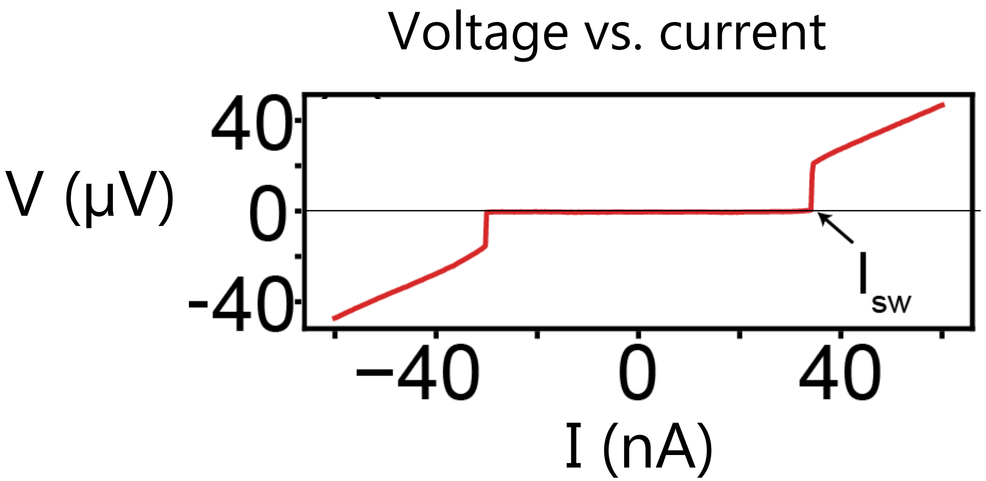




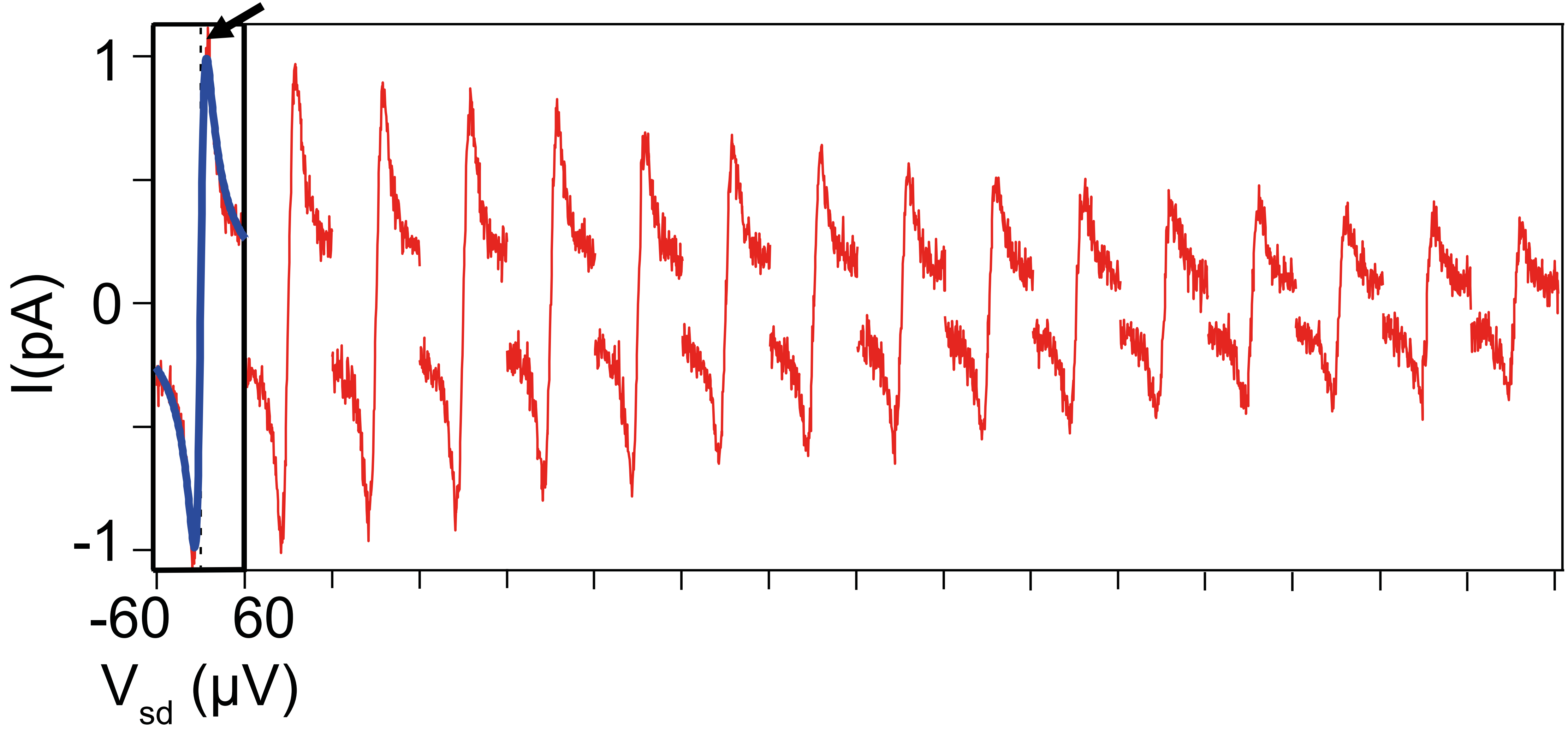
Also: Estrada Saldaña,...,Nygård, J. (2018). Two-Impurity Yu-Shiba-Rusinov States in Coupled Quantum Dots. arXiv, 1812.09303.

The Josephson effect

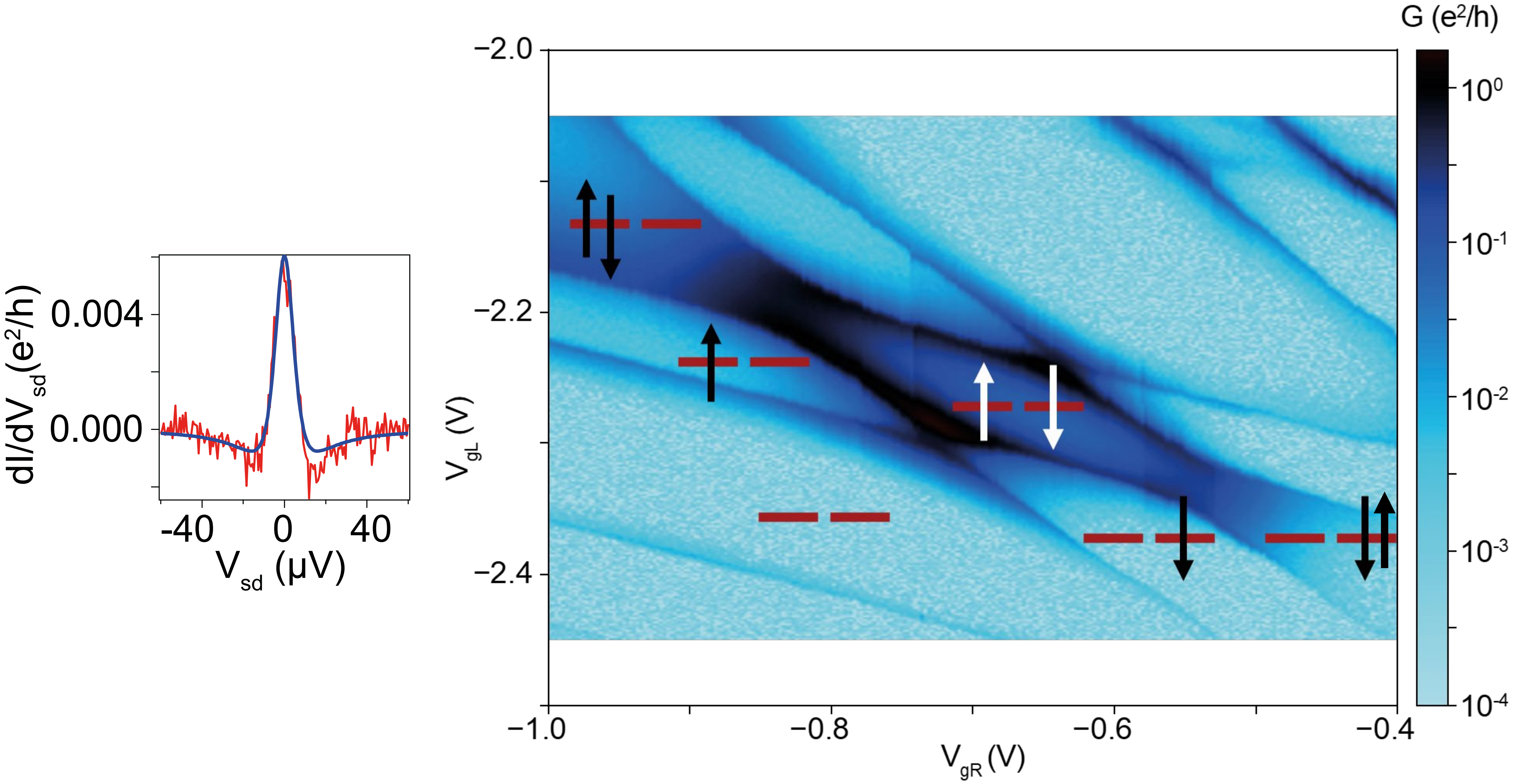




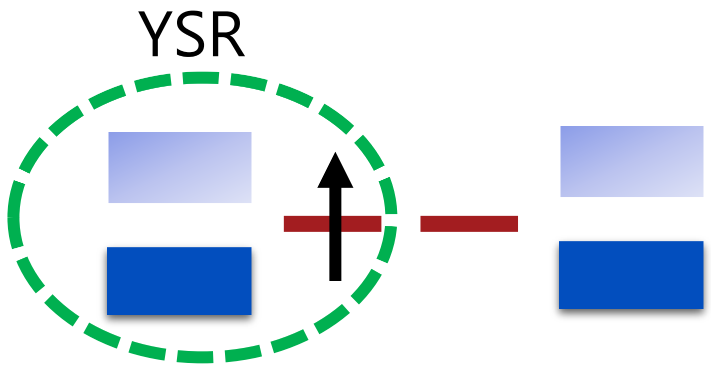
Josephson effect in our S-DQD-S device

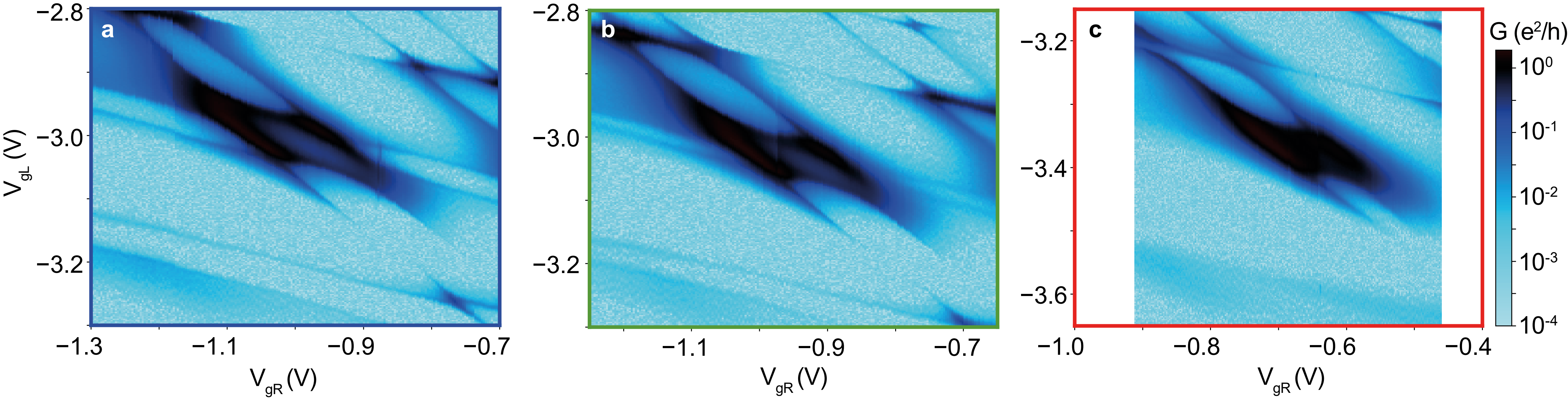


Also: Estrada Saldaña,...,Nygård, J. (2018). Two-Impurity Yu-Shiba-Rusinov States in Coupled Quantum Dots. arXiv, 1812.09303.

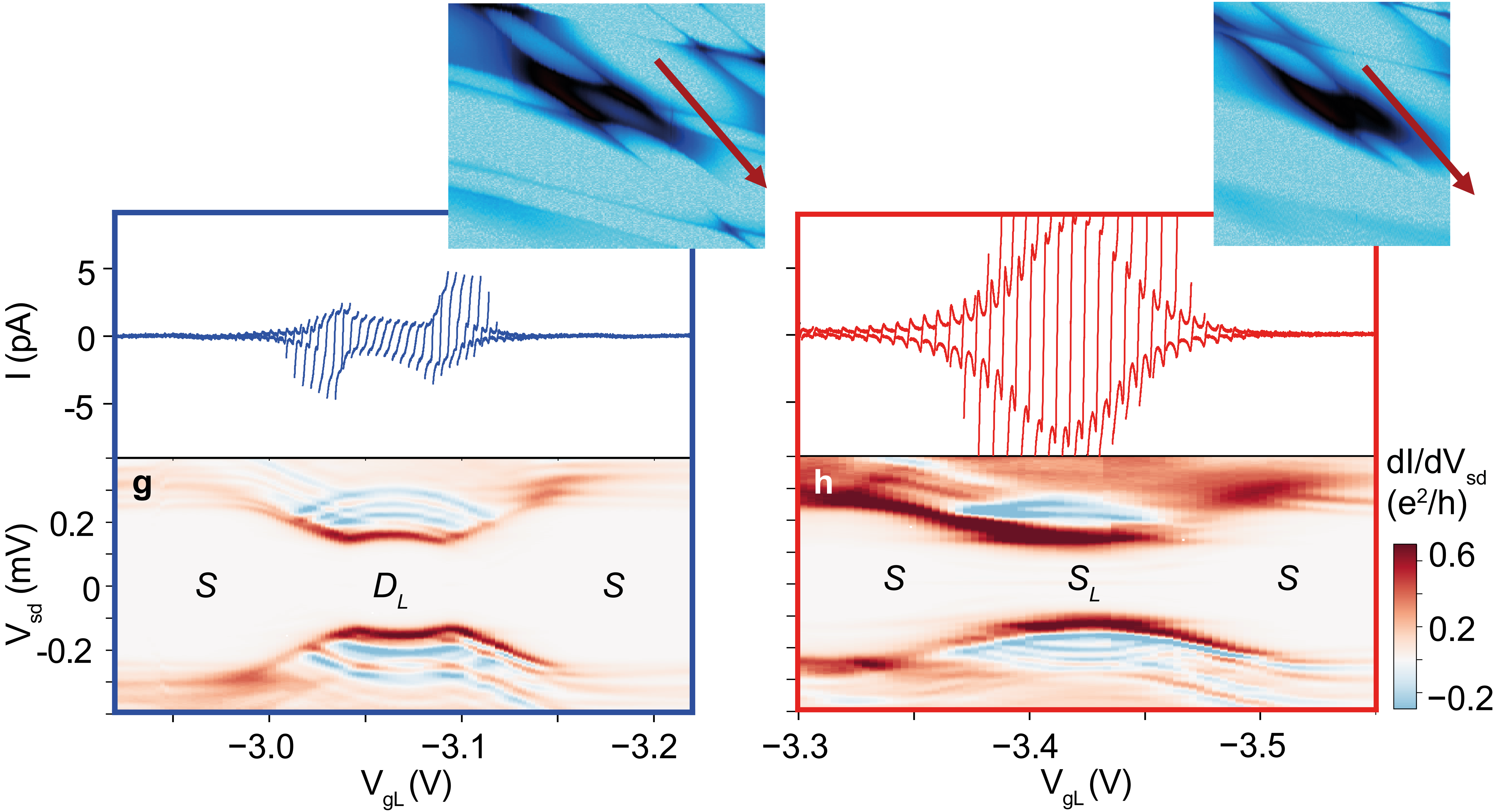


dI/dV_sd(e²/h)
0.004
0.000
-40
0
40
V_sd (μV)
G (e²/h)
−2.0
−2.2
−2.4
V_gL (V)
−1.0
−0.8
−0.6
−0.4
V_gR (V)
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴





Estrada Saldaña,...,Nygård, J. (2018), arXiv, 1812.09303.


I (pA)
5
0
-5
V_{sd} (mV)
0.2
0
-0.2
g
h
S
D_L
S
S
S_L
S
−3.0
−3.1
−3.2
−3.3
−3.4
−3.5
V_{gL} (V)
V_{gL} (V)
dI/dV_{sd} (e^2/h)
0.6
0.2
−0.2

More details at:

PHYSICAL REVIEW LETTERS **121,** 257701 (2018)

Supercurrent in a Double Quantum Dot

J. C. Estrada Saldaña,[1] A. Vekris,[1] G. Steffensen,[1] R. Žitko,[2,3] P. Krogstrup,[1,4] J. Paaske,[1]
K. Grove-Rasmussen,[1] and J. Nygård[1,*]

Also: Estrada Saldaña,...,Nygård, J. (2018). Two-Impurity Yu-Shiba-Rusinov States in Coupled Quantum Dots. arXiv, 1812.09303.

Overview of additional nanowire devices

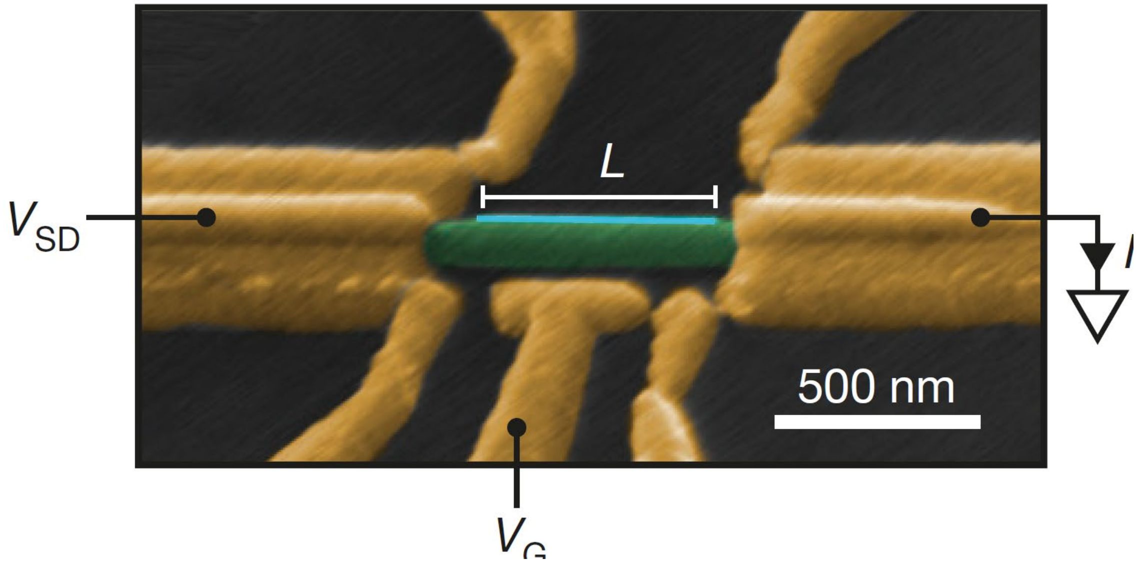
1. Superconducting islands in nanowires

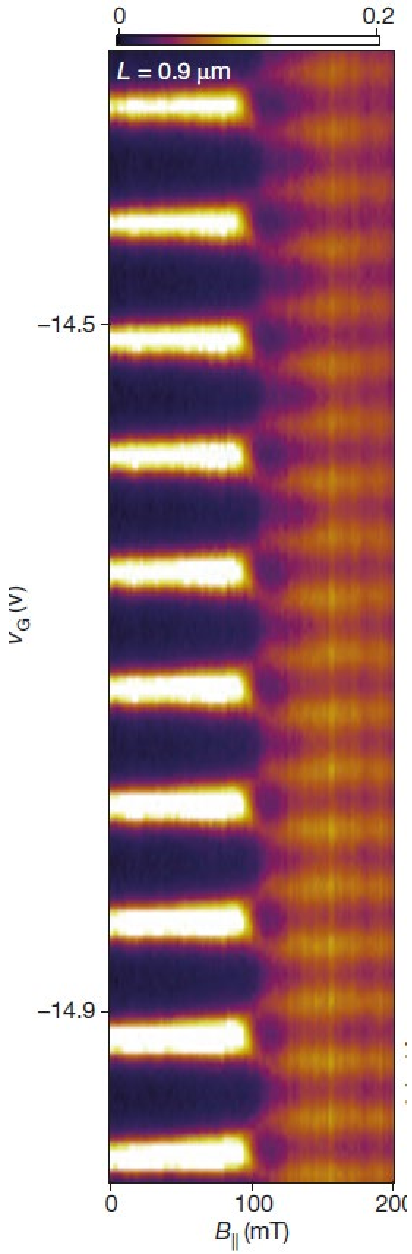
LETTER

doi:10.1038/nature17162

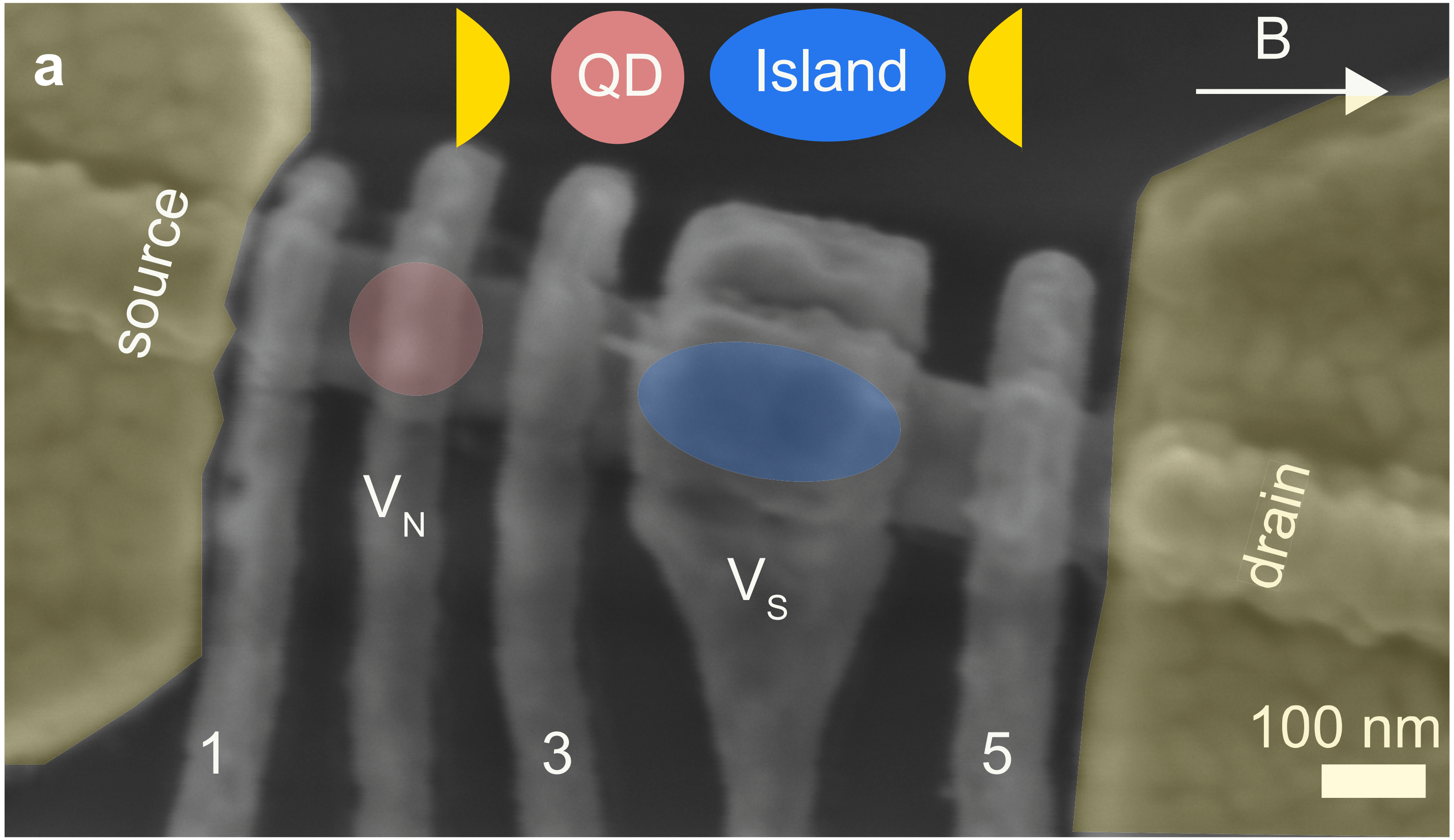
Exponential protection of zero modes in Majorana islands

S. M. Albrecht[1]*, A. P. Higginbotham[1,2]*, M. Madsen[1], F. Kuemmeth[1], T. S. Jespersen[1], J. Nygård[1], P. Krogstrup[1] & C. M. Marcus[1]





Our work



SpinScreen

Estrada Saldaña et al., in preparation

2. The Little Parks effect in nanowires

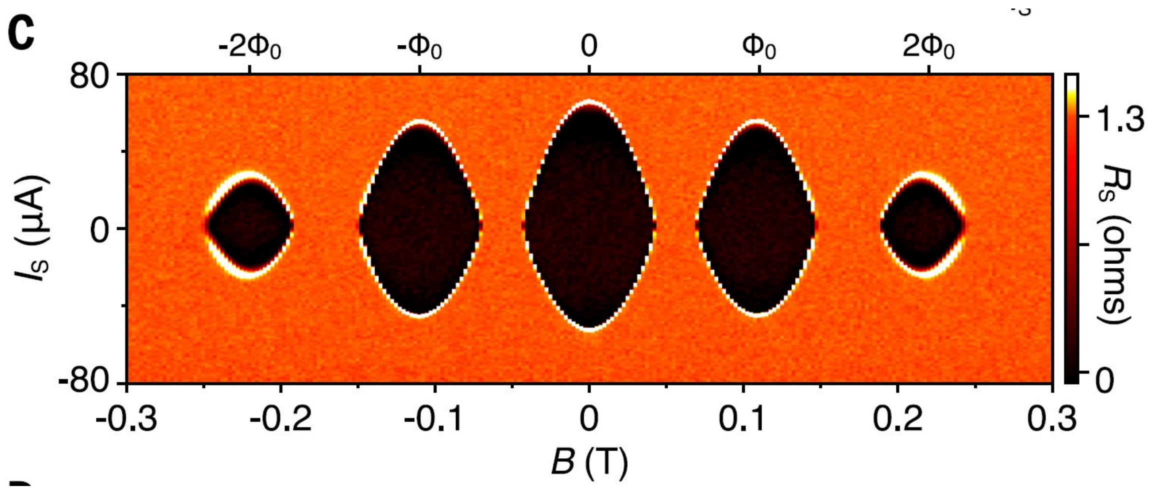
RESEARCH

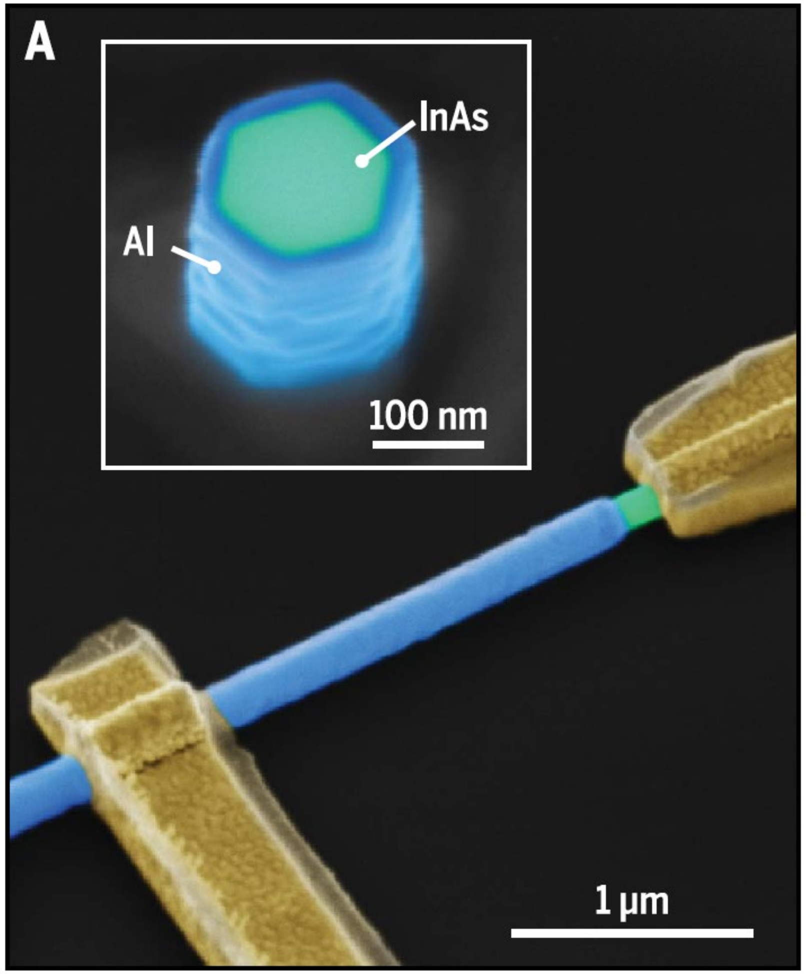
RESEARCH ARTICLE SUMMARY

TOPOLOGICAL MATTER

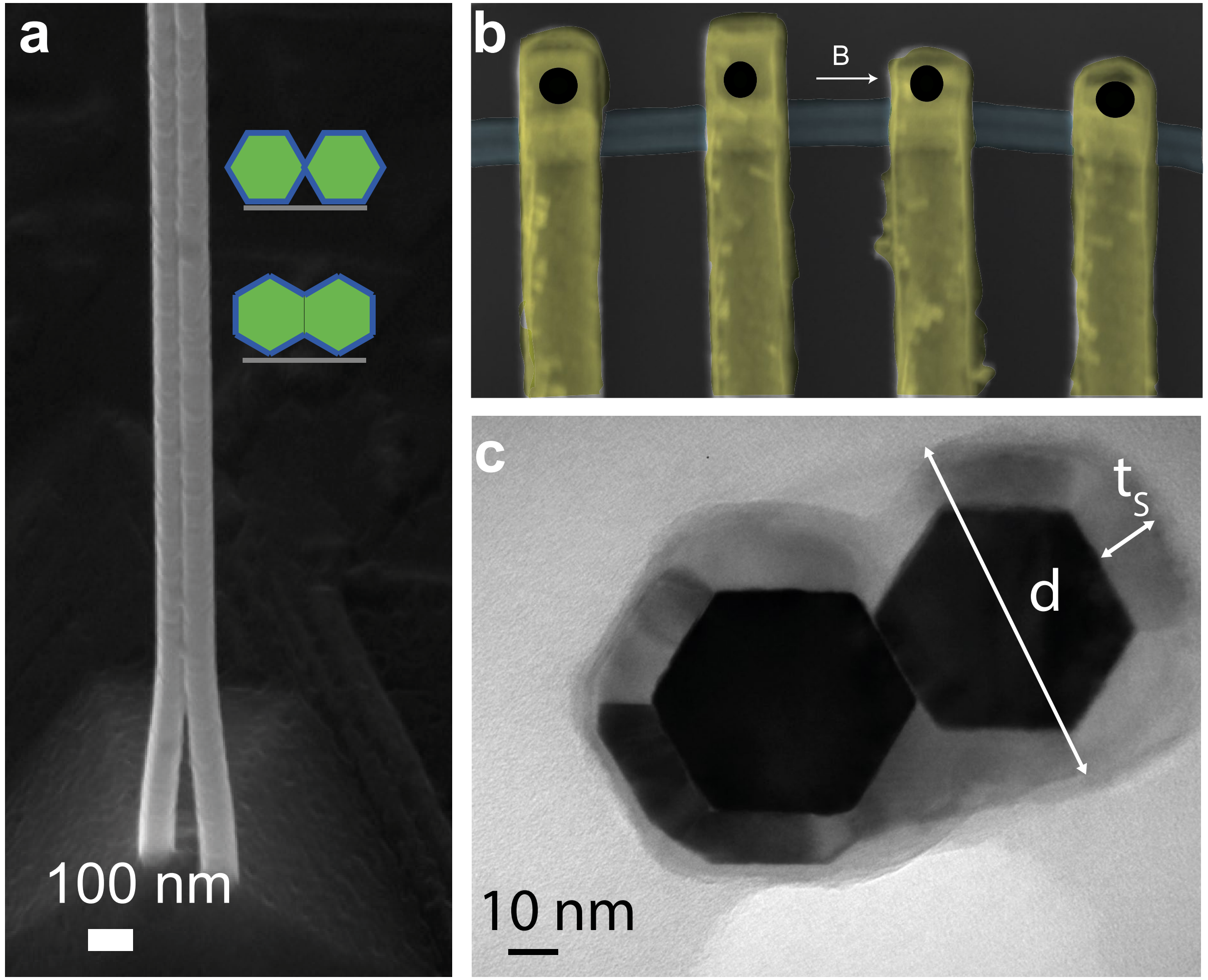
Flux-induced topological superconductivity in full-shell nanowires

S. Vaitiekėnas, G. W. Winkler, B. van Heck, T. Karzig, M.-T. Deng, K. Flensberg, L. I. Glazman, C. Nayak, P. Krogstrup, R. M. Lutchyn*, C. M. Marcus*





Our work



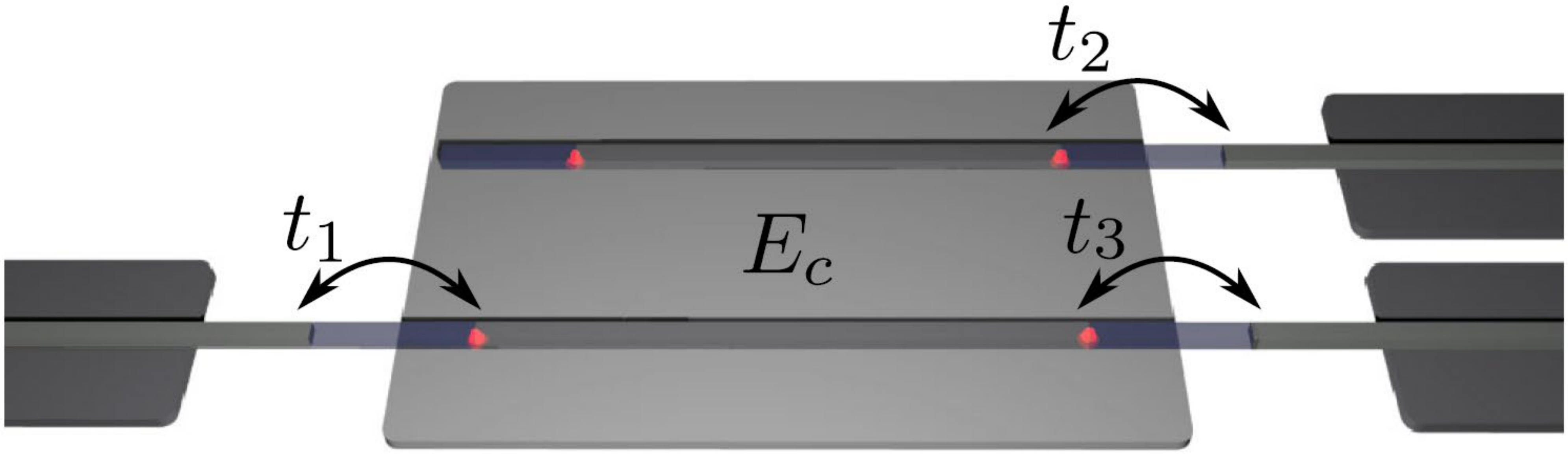
Vekris, Estrada Saldaña et al., in preparation

3. Double-nanowire superconducting islands

PRL **109,** 156803 (2012) PHYSICAL REVIEW LETTERS

Topological Kondo Effect with Majorana Fermions

B. Béri and N. R. Cooper



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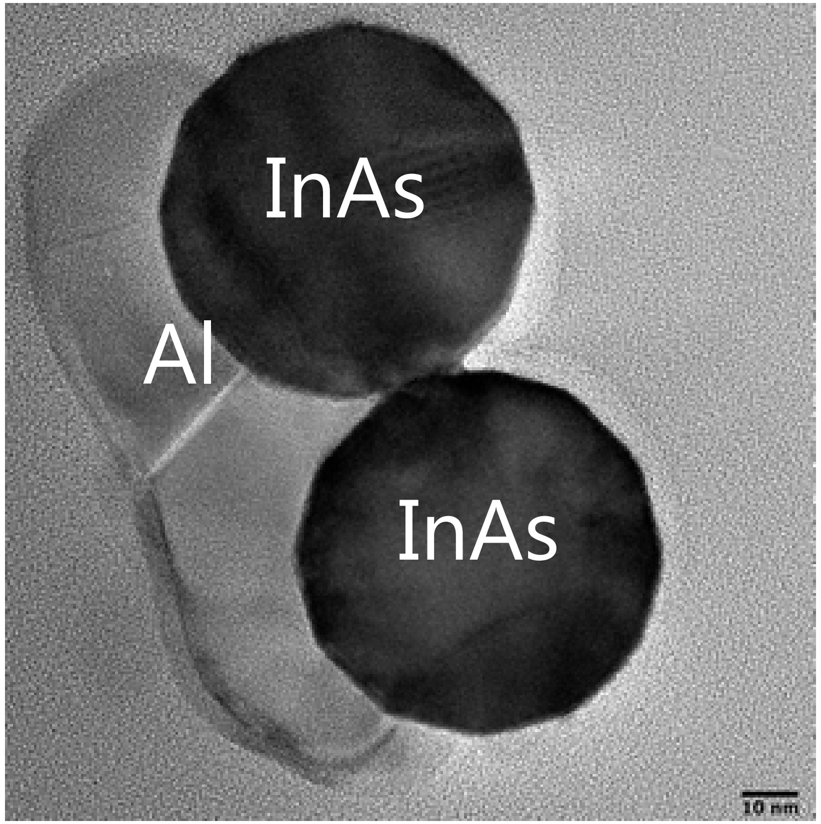
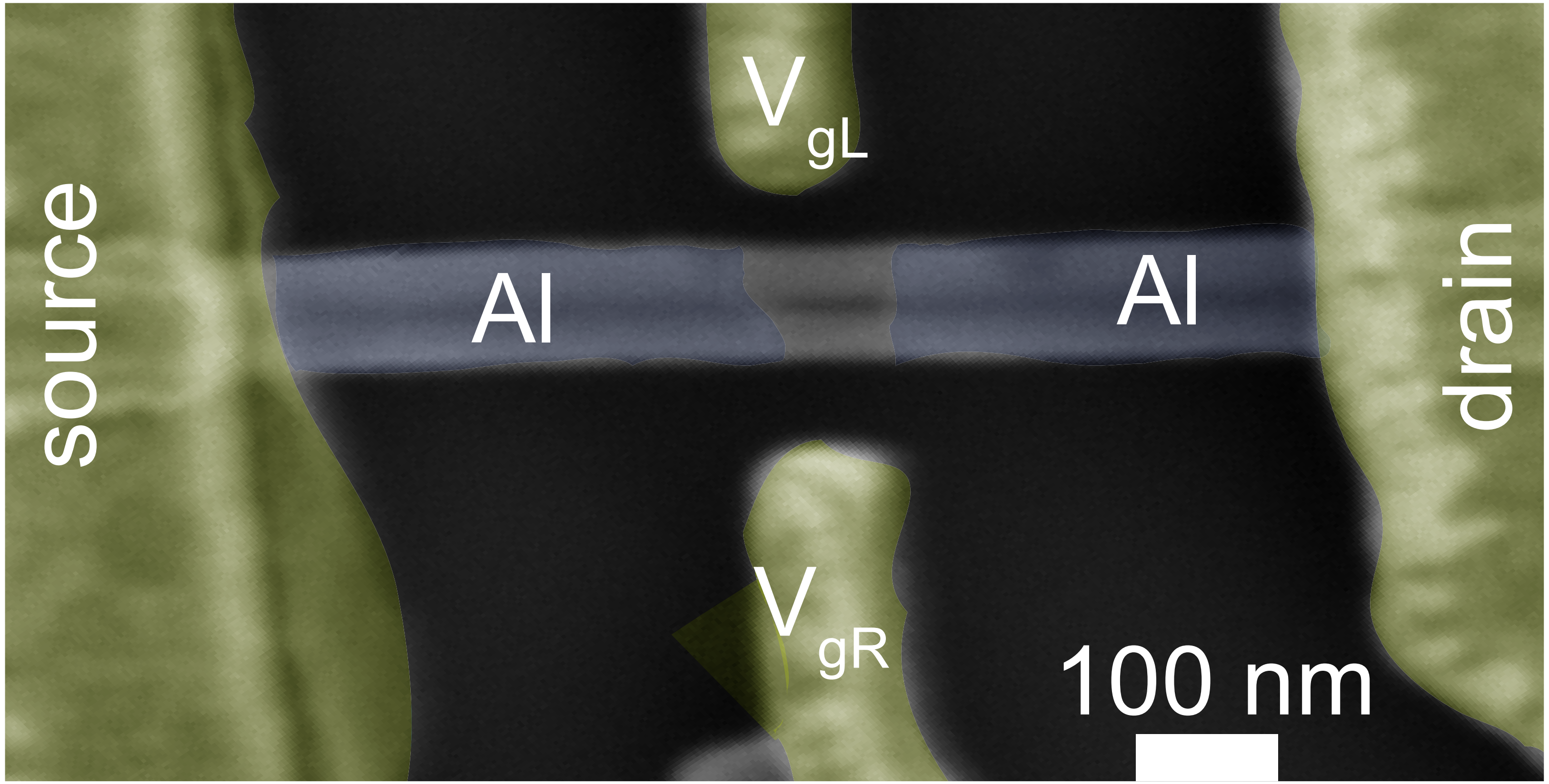
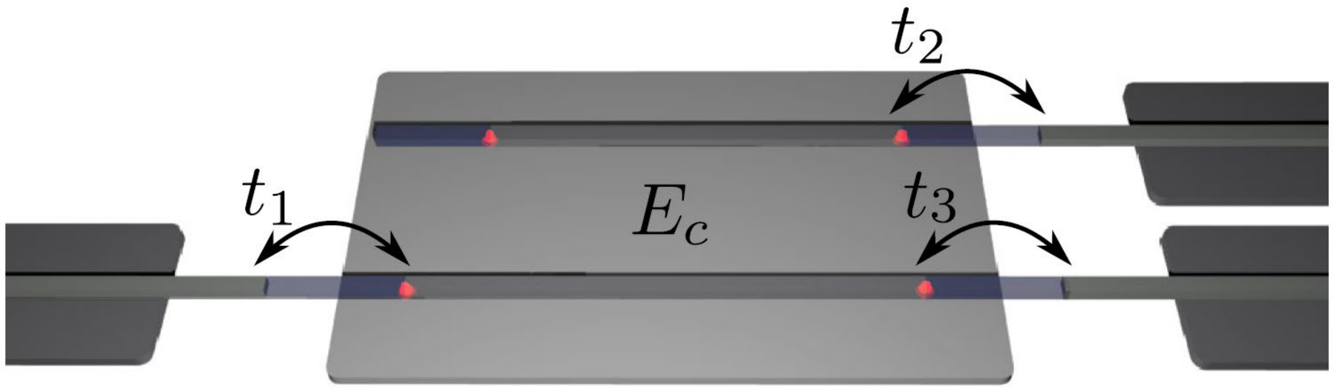




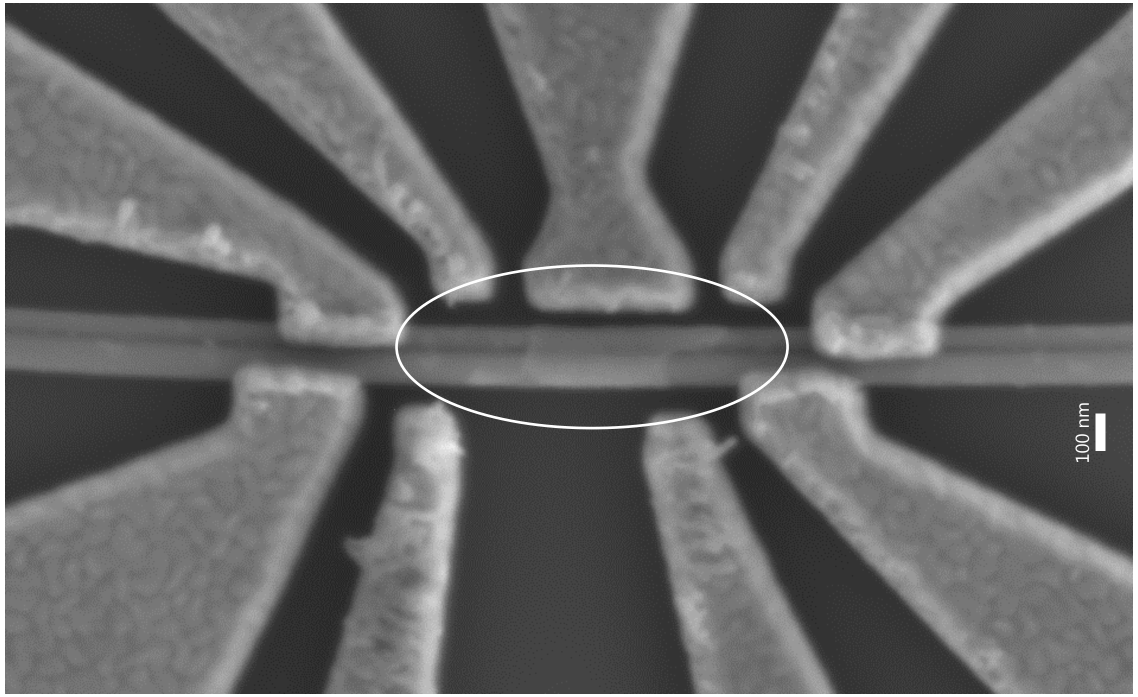
Vekris, Estrada Saldaña et al., in preparation

Our work

Model



Device



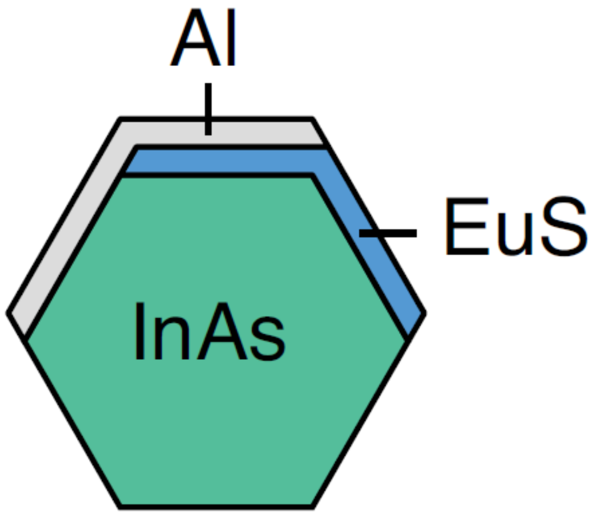
Ongoing experiment...

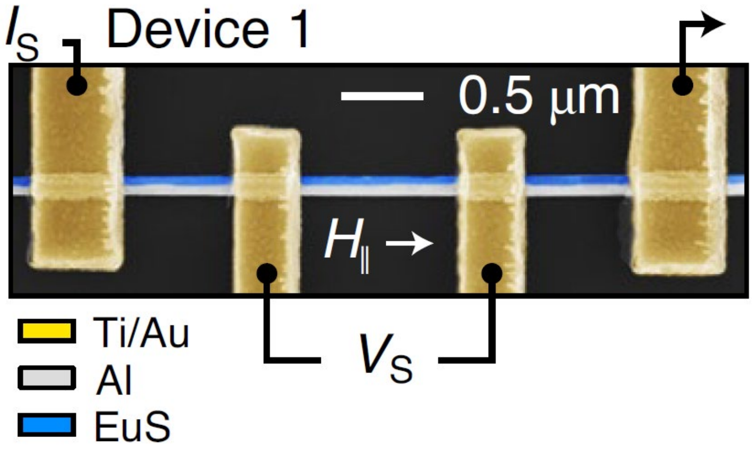
4. Ferromagnet-superconductor-nanowire hybrids

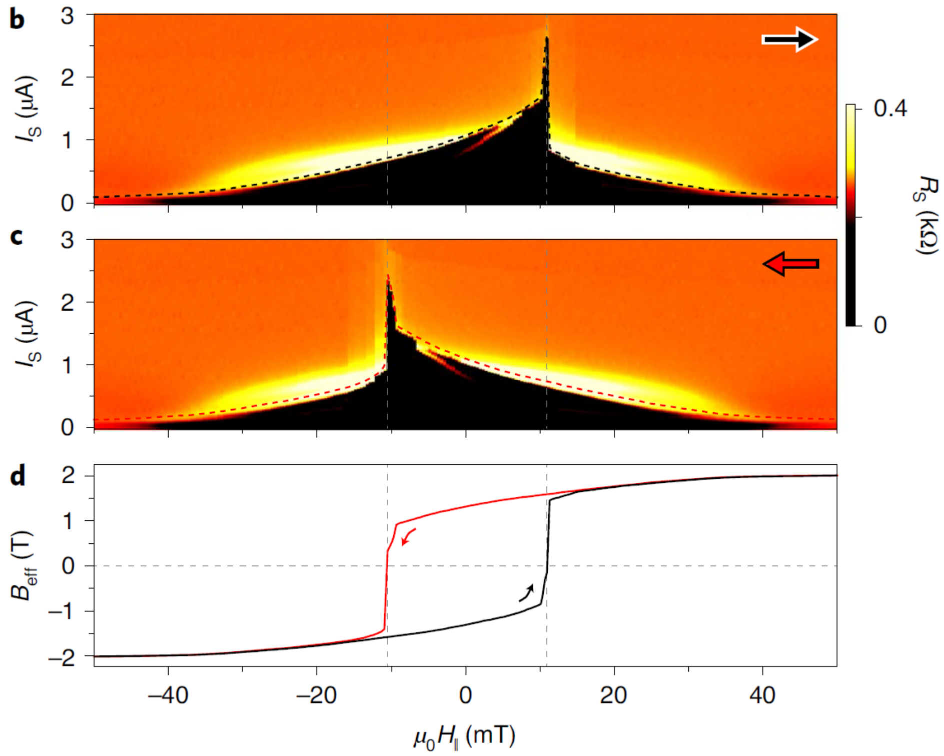
nature physics
LETTERS
https://doi.org/10.1038/s41567-020-1017-3
Check for updates

Zero-bias peaks at zero magnetic field in ferromagnetic hybrid nanowires

S. Vaitiekėnas[1,2], Y. Liu[1,3], P. Krogstrup[1,3] and C. M. Marcus[1,2]







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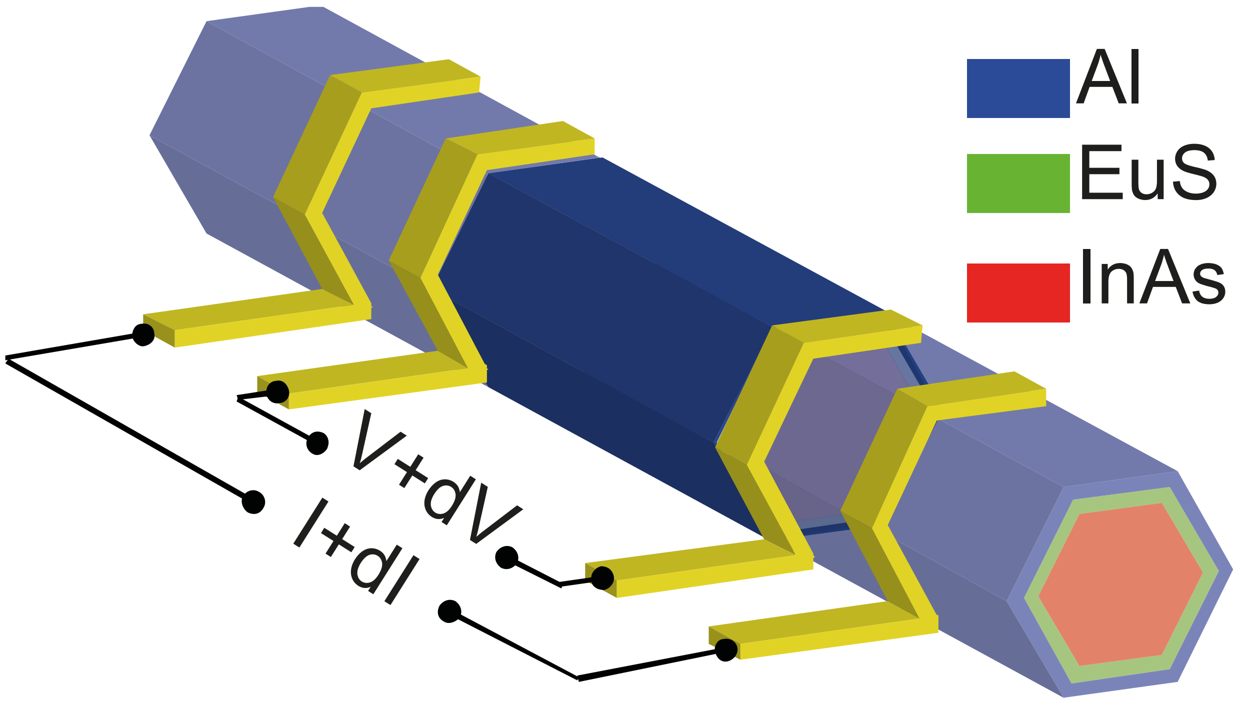
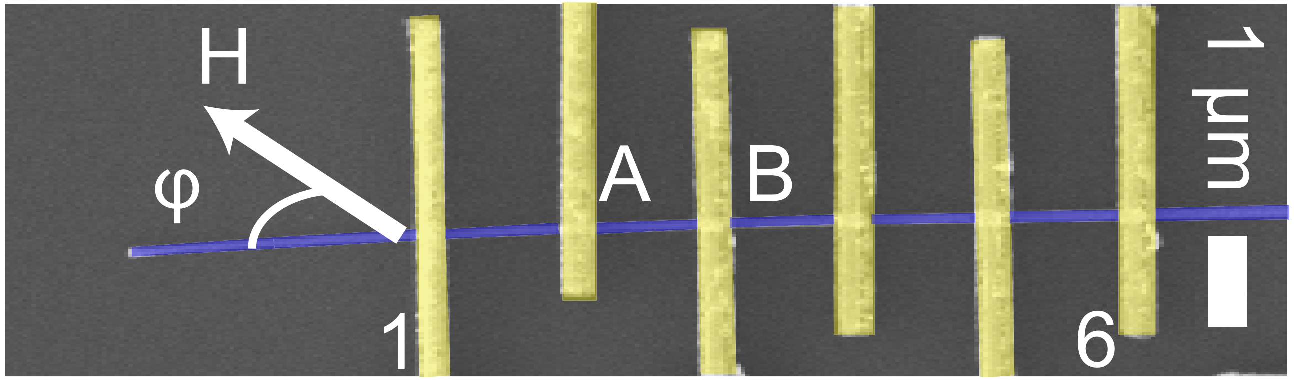
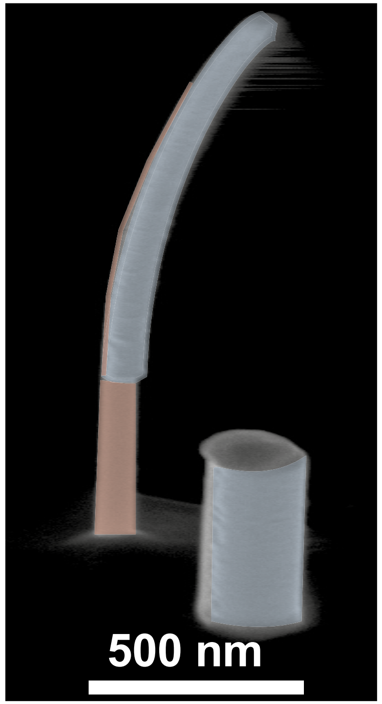


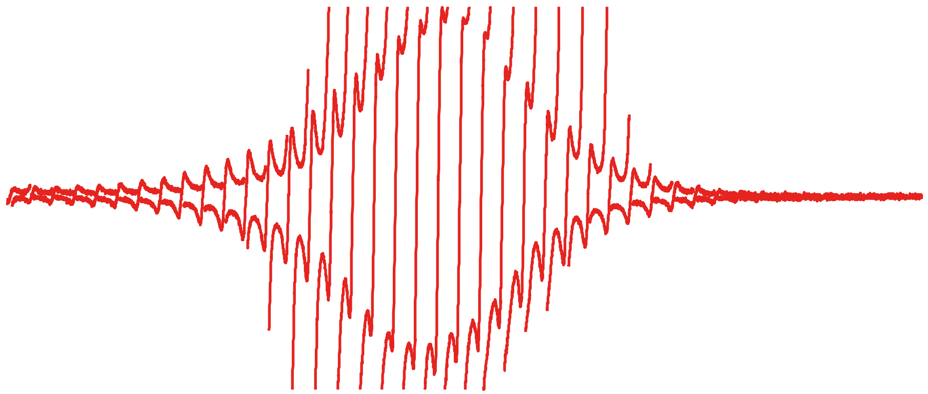


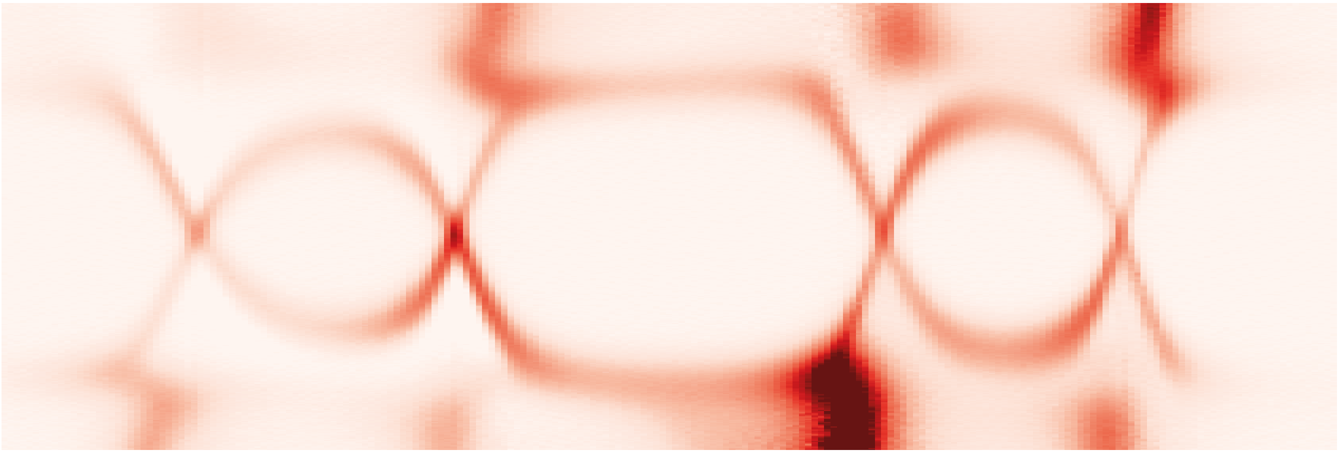
Estrada Saldaña et al., in preparation

Summary

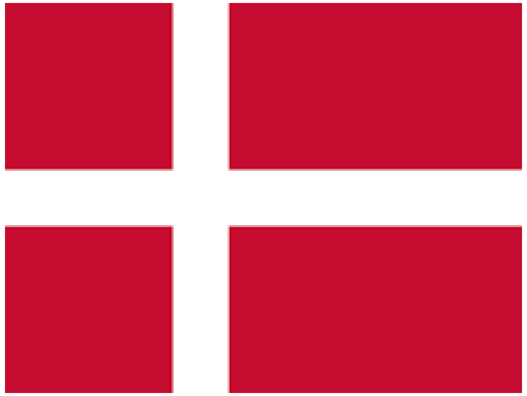
- Nanowires are ultra-flexible platforms for condensed matter physics.

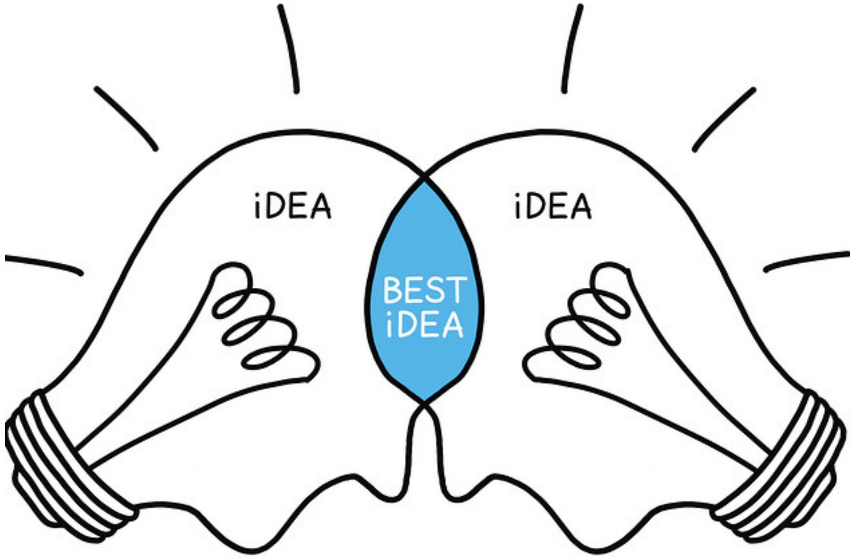






We are always interested in theoretical insights
and in collaborations with experimentalists.





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