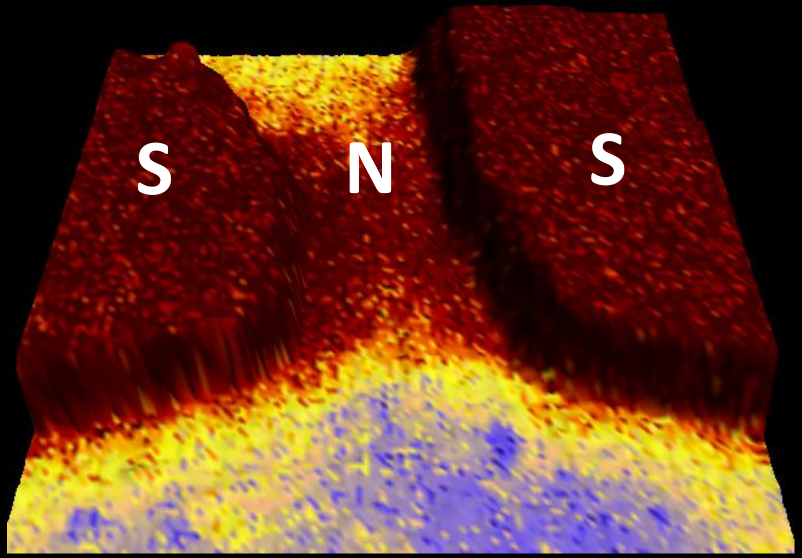
Josephson vortex as a logical state of low-dissipative devices

Vasily Stolyarov

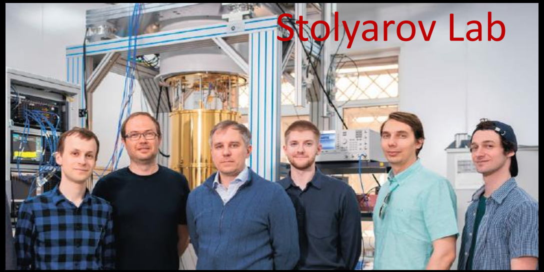


MEZO Center for Advanced Mesoscience & Nanotechnology

CoLab

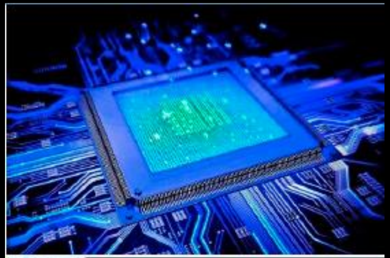
ВНИИА

MIPT

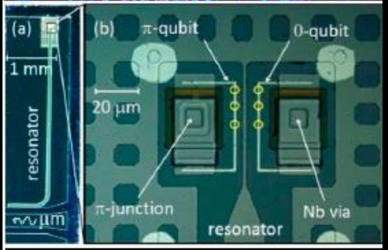


Like in Manchester but Advanced …

Superconducting Quantum technology



Superconducting Digital electronics



Superconducting Neuromorphic systems

Topologically protected systems

Center for Advanced Mesoscience & Nanotechnology

Laboratory of Topological Quantum Phenomena in Superconducting Systems

Opened in 2014.

ВНИИА

MIPT

Head of lab.
Prof
Golubov A.A.

Chief Researcher
Prof
Stolyarov V.S.

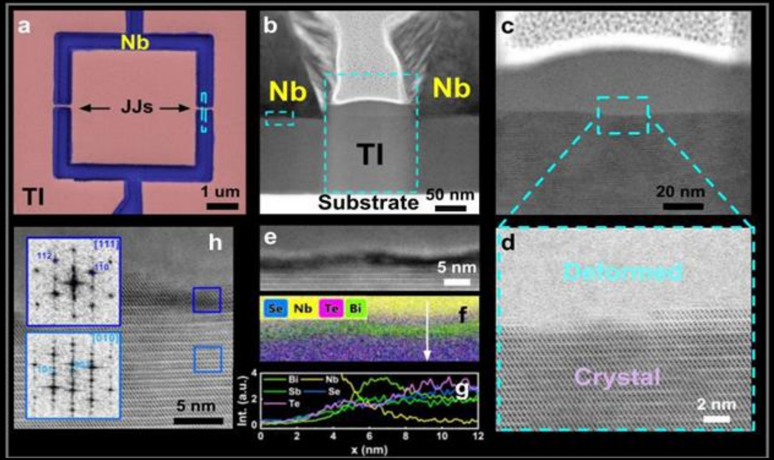
Leading Researcher
Prof
Golovchanskiy I.A.

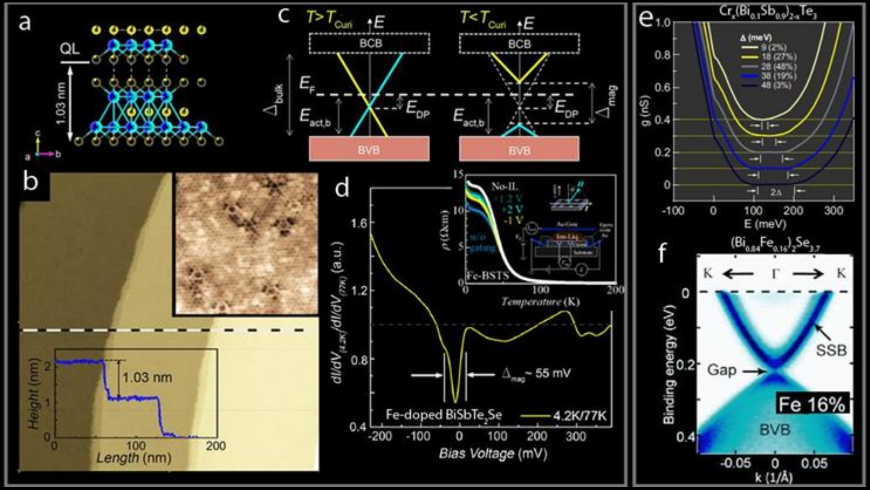
Senior Researcher
Dr
Skrybina O.V.

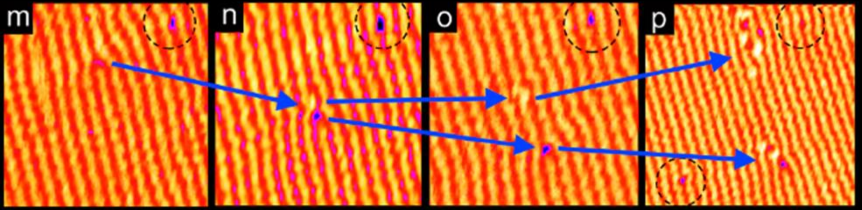
Junior Researcher
applicant
Shishkin A.G.

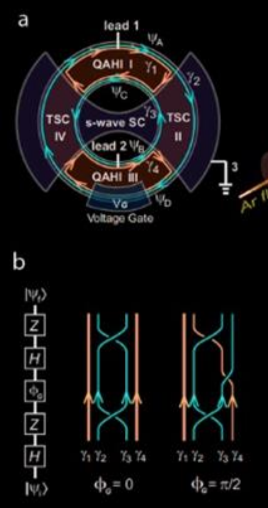
Junior Researcher
PhD student
Kalashnikov D.C.

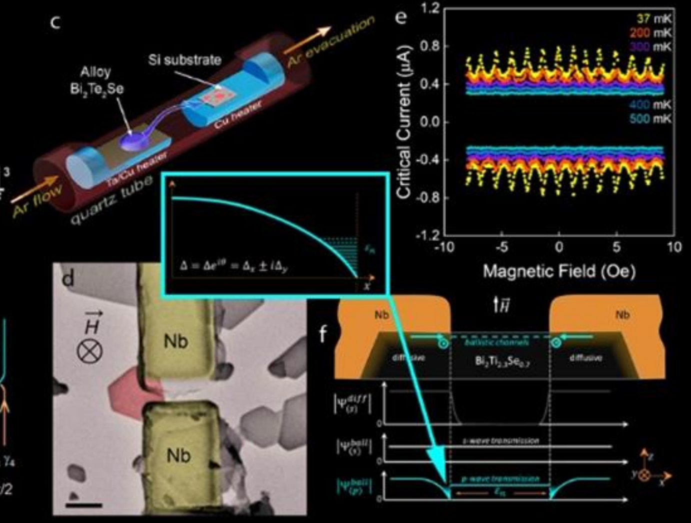
...

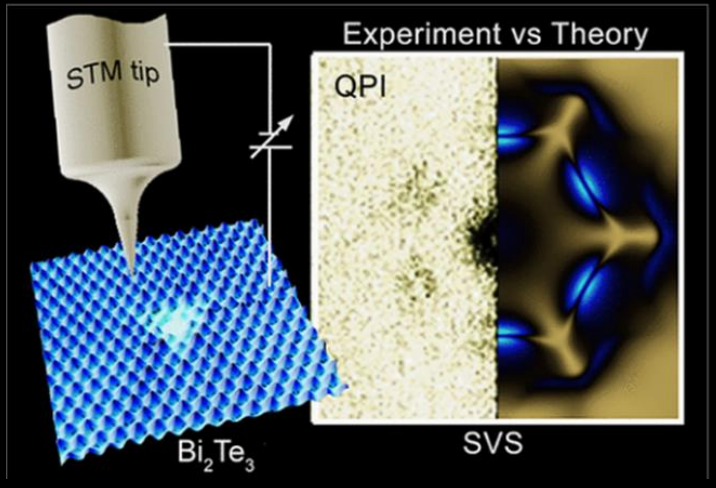












Opened in 2020 г.

...

Head of lab.
Prof
Stolyarov V.S.

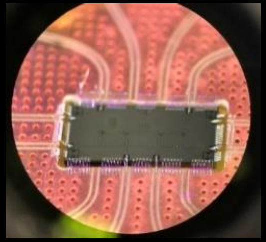
Leading Researcher
Dr
Lebedev A.V.

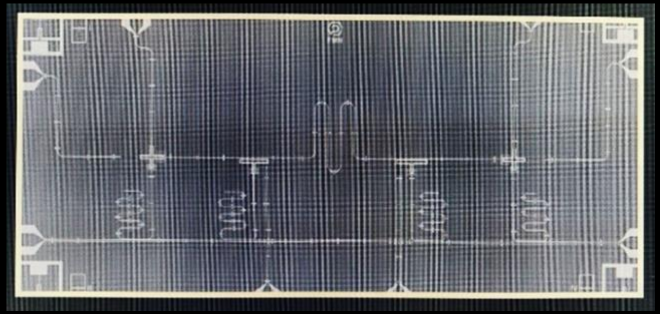
Leading Researcher
Prof
Soloviev I.I.

Senior Researcher
Dr
Rujitskiy V.I.

Senior Researcher
Dr
Bakurskiy S.V.

Junior Researcher
PhD student
Polevoy K.B.





1. Tunable high speed atomic rotor in Bi2Se3 revealed by current noise. *ACS Nano*, 2021
2. Reconfigurable Josephson phase shifter. *Nano Letters*, 2021.
3. Approaching deep-strong on-chip photon-to-magnon coupling. *Physical Review Applied*, 2021
4. Ultrastrong photon-to-magnon coupling in multilayered heterostructures involving superconducting coheren layers. *Science Advances* 2021.

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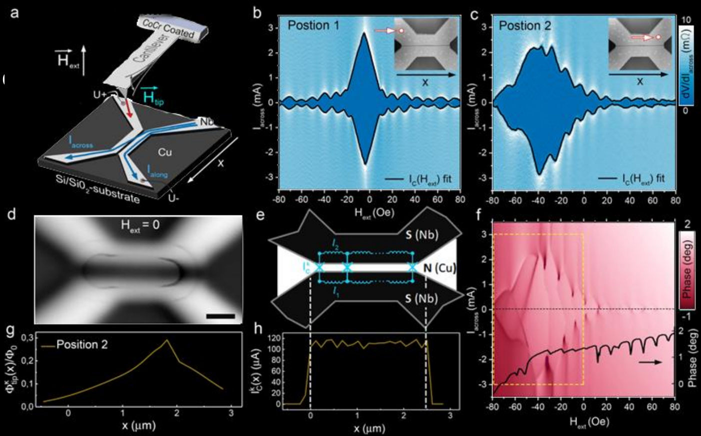
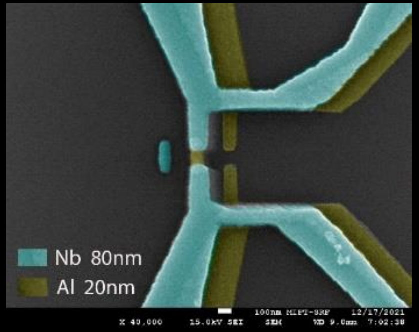
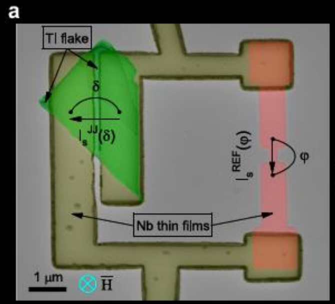
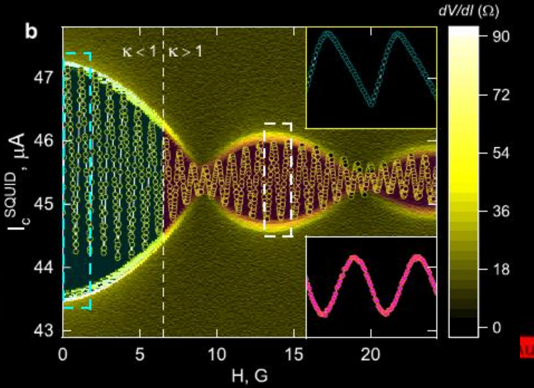
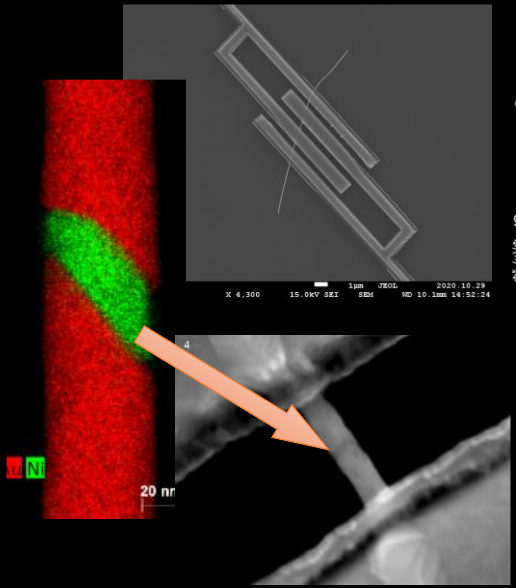
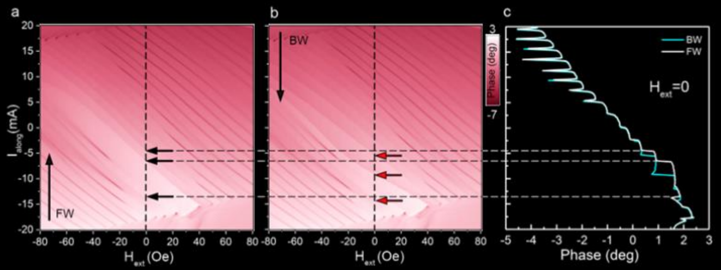












Center for Advanced Mesoscience & Nanotechnology

Laboratory of spin phenomena in superconducting nanostructures and devices

Opened in 2022

MIPT

Head of lab.
Prof
Bobkova I.V.

Senior Researcher
Dr
Bobkov A.M.

Senior Researcher
Dr
Rahmonov I.R.

Junior Researcher
PhD student
Rabinovich D.S.

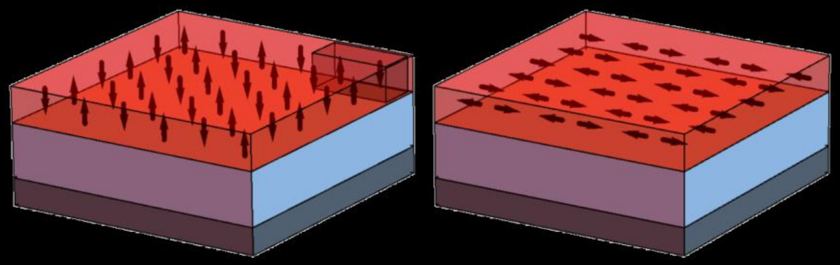
Junior Researcher
PhD student
Karabasov T.

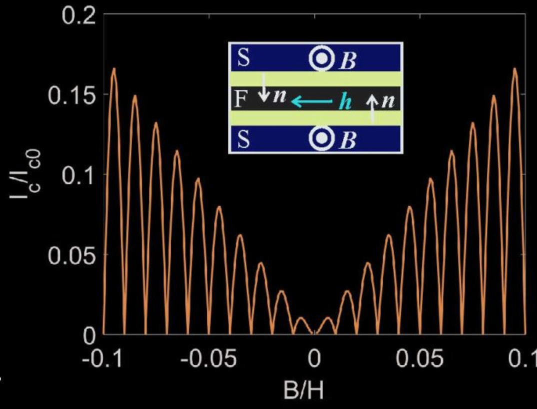
Student
Gordeeva V.M.

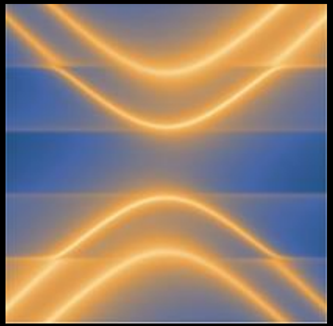
student
Bobkov G.A.

student
Nekrasov B.M.

student
Yanovskaya A.S.







1. Dynamic Spin-Triplet Order Induced by Alternating Electric Fields in Superconductor-Ferromagnet-Superconductor Josephson Junctions, **Phys. Rev. Lett.**
2. Néel proximity effect at antiferromagnet/superconductor interfaces, **Phys. Rev. B**
3. Magnon-cooparons in magnet-superconductor hybrids, **Communications Materials**
4. Renormalization of antiferromagnetic magnons by superconducting condensate and quasiparticles, **Phys. Rev. B**

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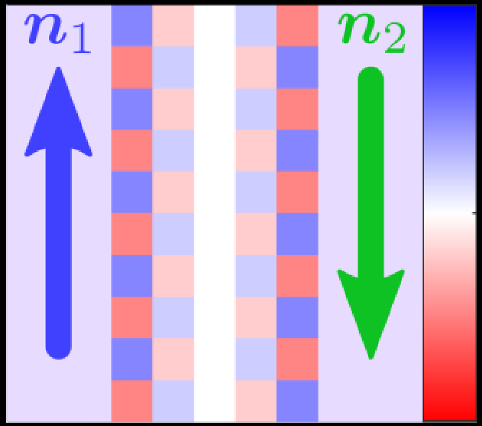
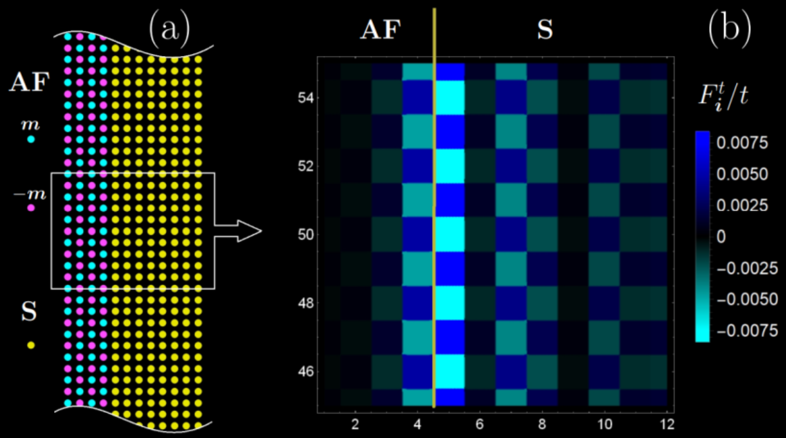
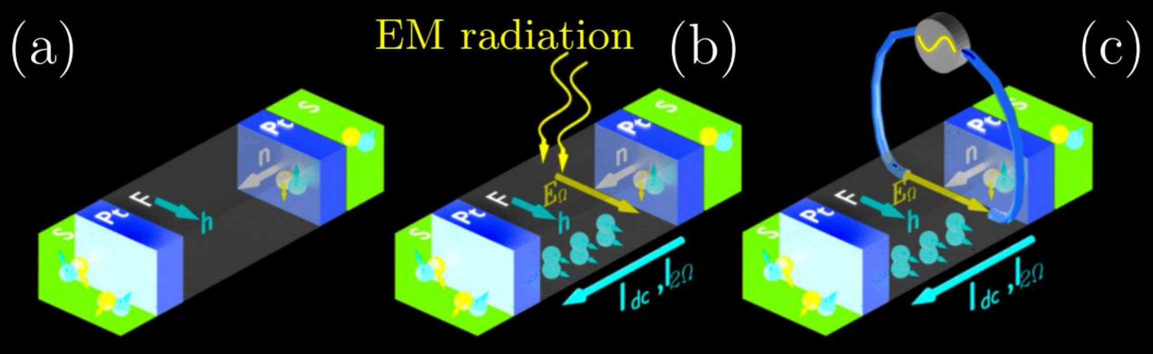






Center for Advanced Mesoscience & Nanotechnology

Laboratory of Photoelectron Spectroscopy of Quantum Functional Materials

Opened in **2023**

Санкт-Петербургский государственный университет

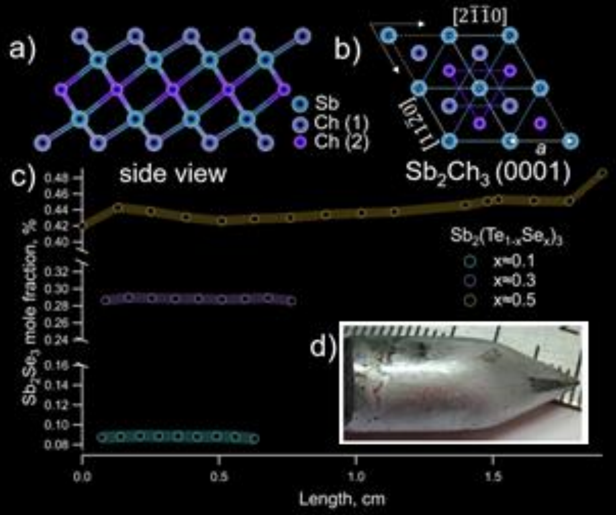
Head of lab.
Dr
Frolov A.S.

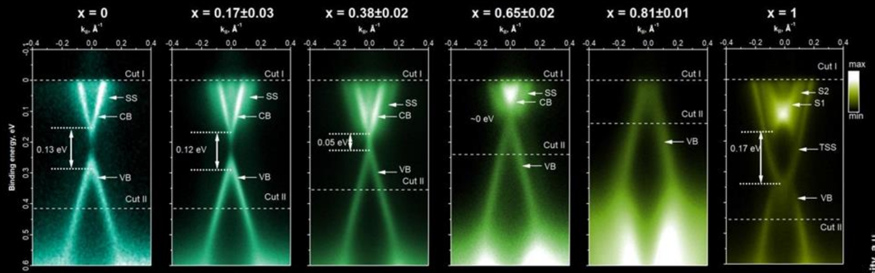
Leading Researcher
Prof
Yashina L.V.

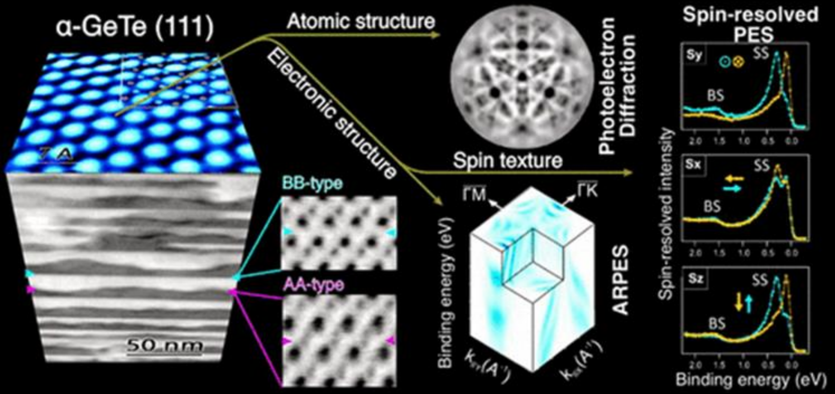
Leading Researcher
Prof
Usachev D.Yu.

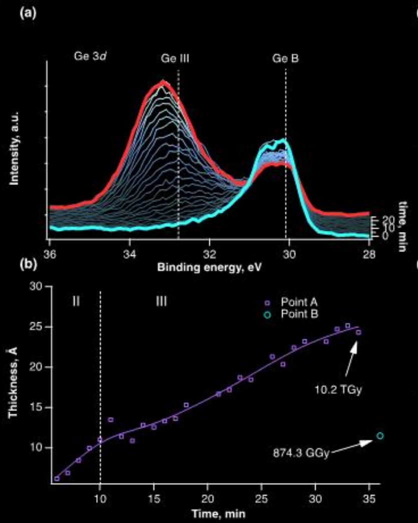
Senior Researcher
Dr
Klimovskih I.I.

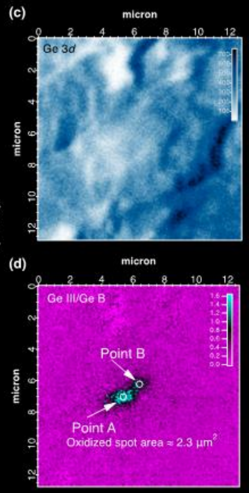
...









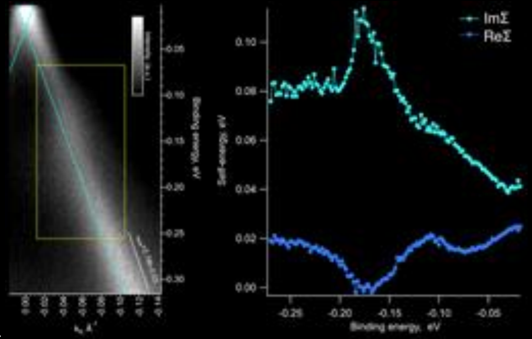


A. S. Frolov et al., Acs Nano. 16, 20831–20841 (2022).

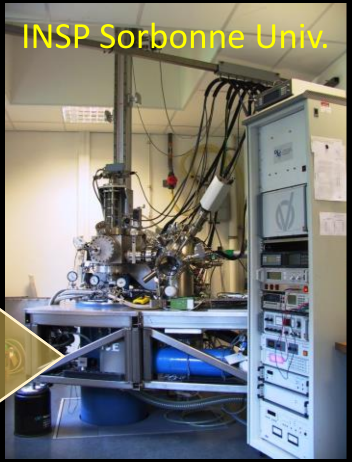
A. S. Frolov et al., Nanoscale. 14, 12918–12927 (2022).

N. V. Vladimirova et al., Surfaces Interfaces. 36, 102516 (2023).

A.S. Frolov et al. Magnetic Dirac semimetal state of (Mn, Ge) Bi_2Te_4 //arXiv preprint arXiv:2306.13024. – 2023.



ESPCI
INSP
ISSP RAS

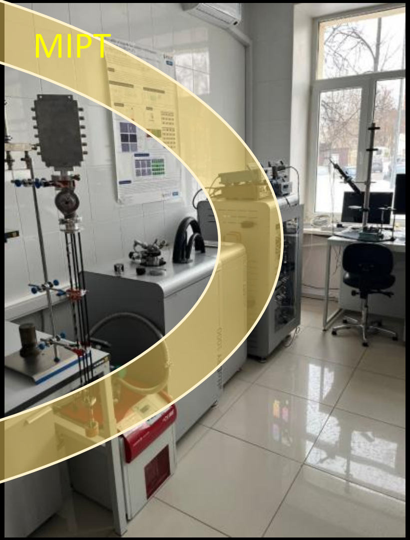


He^3-STM 300 мК 10 Тл

JT-SPM 1 K

JT-SPM 1 K 3 Тл

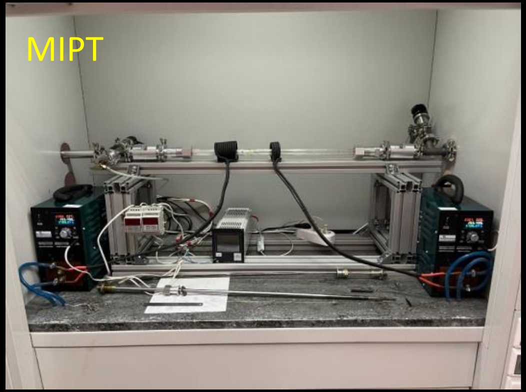
LH 4K 20 л/сут.



2 MFM 1.2/4K 9T

Developed research complex 2010-2023

UHV-LS-204 6-magnetrons



Ar-PVD 900-300C

2 BlueFors 20мК 10T

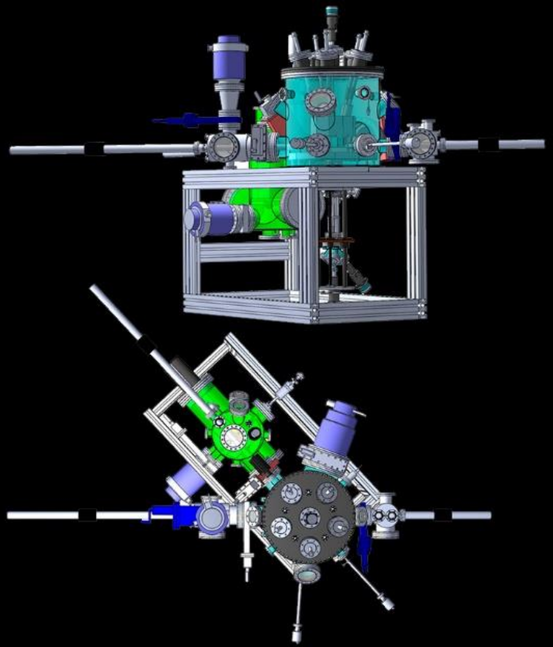
+ Equipment sharing Center at MIPT

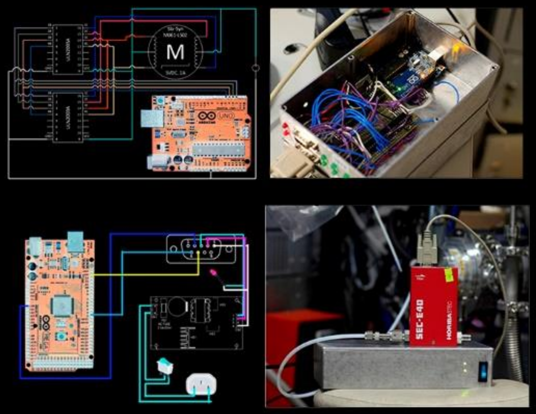
- **UHV-magnetron sputtering**

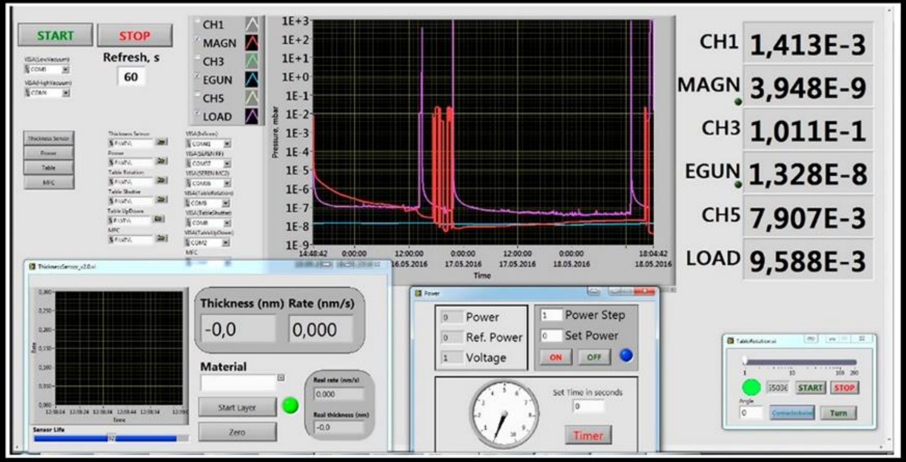
P=10 $^{-9}$ mbar
5 magnetrons
5 e-beam sources
In-situ etching,
Materials: Al, Nb, MoRe, Pb, Ta, Cu, Pt, Au , CuNi, Ni, PdFe, Co, Fe

Was created during my PhD at the lab of

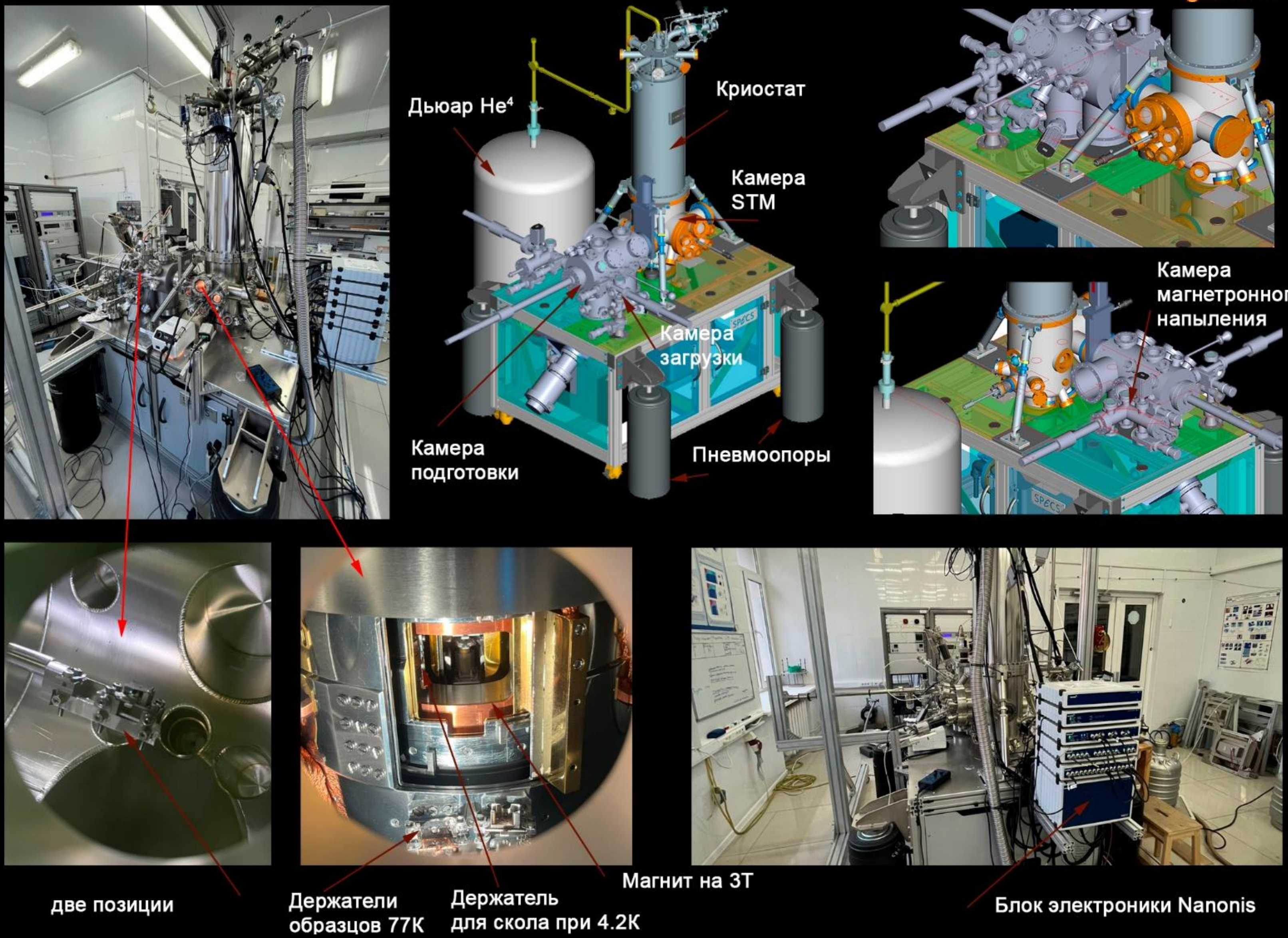
Prof
Ryazanov V.V.







- **JT-STM SPECS (Joule-Thomson**
- **Scanning Tunneling Microscope)**
- P≤10^{-10} mbar, T = 1.2 K,
- Magnetic Field up to 3 T
- Scanning area 2 mkm^2

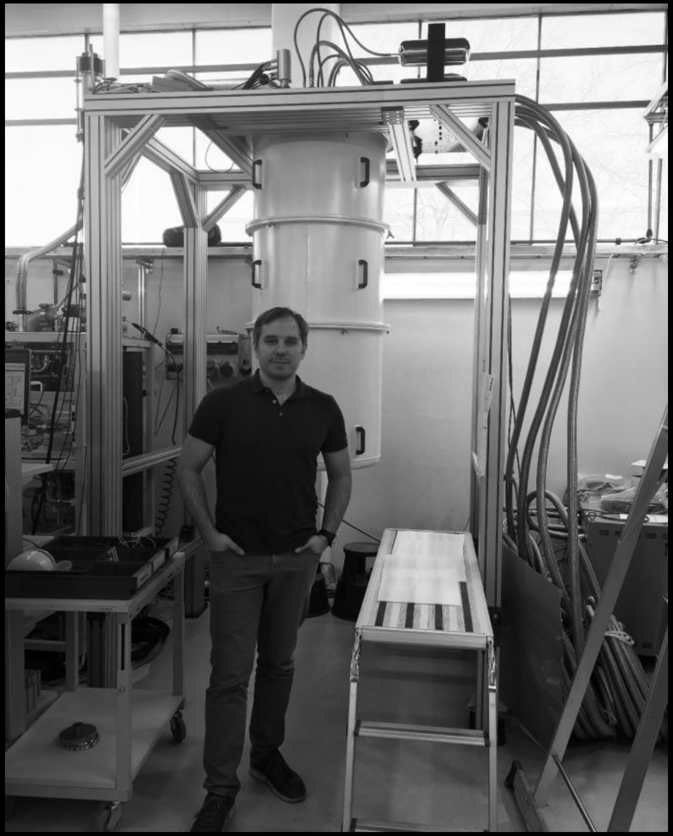


MEZO ВНИИА MIPT

- **AFM/MFM AttoDry1000/2100 (Attocube, Pulse Tube)** T = 1.2 K - 150 K, scan area 20 mkm^2, H=9 T

- Dilution refrigerators BlueFors LD250 10мК 10T and XLD1000 10mK 1/1/6T

2014

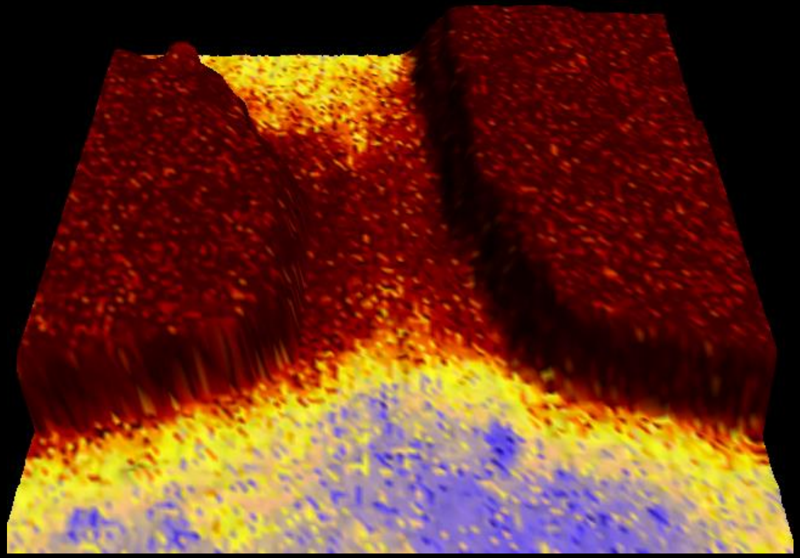


2020

Yesterday..

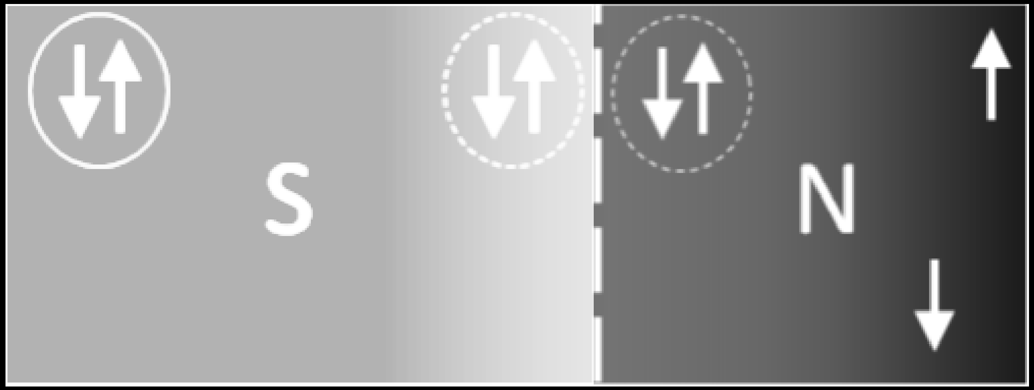
Josephson vortex as a logical state of low-dissipative devices

Part 1: Proximity effect



Superconducting proximity effect

boundary



Superconductor Non supercond. metal

First experimental evidences

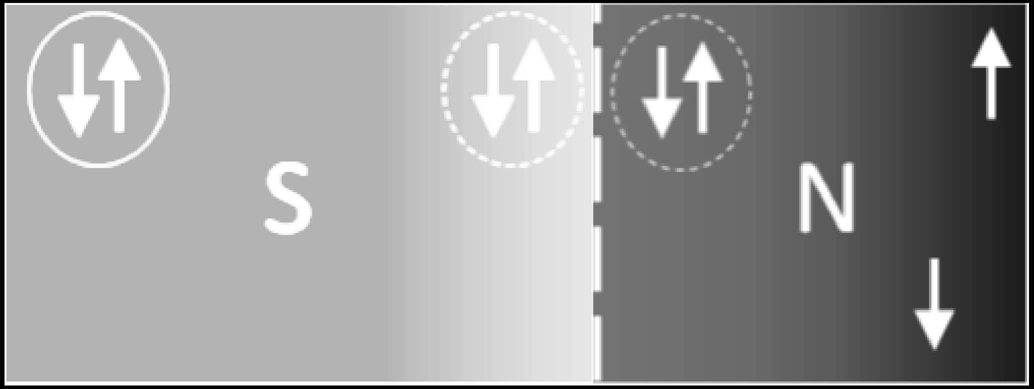
Holm and Meissner (1932)
Bedard and Meissner (1956)
Meissner (1958), (1960)

First theory

De Gennes (1964)
McMillan (1968)
Clarke (1969)
Deutscher and De Gennes (1969)

Superconducting proximity effect

boundary



Superconductor Non supercond. metal

In case of diffuse metal

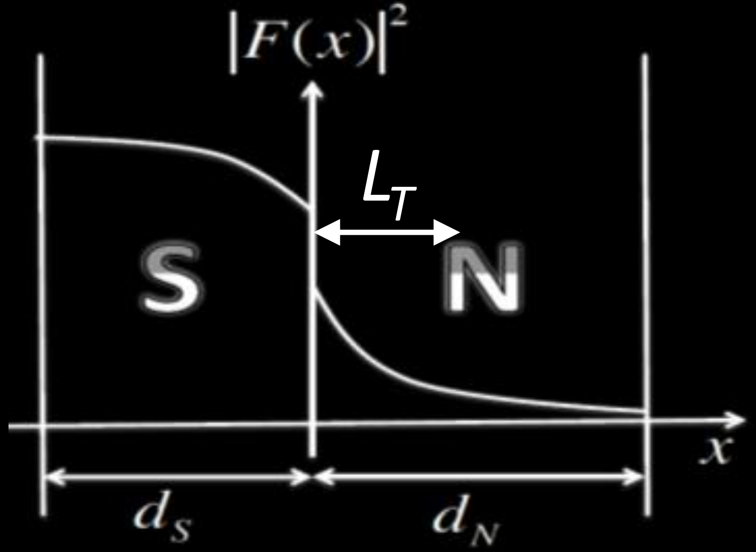
$$L_T = \sqrt{\hbar D_N / (2\pi k_B T)}$$

Cooper pair density

$$F(\vec{r}) = \langle \hat{\psi}_{\uparrow}(\vec{r}) \hat{\psi}_{\downarrow}(\vec{r}) \rangle$$

Order parametr:

$$\Delta(\vec{r}) = V(\vec{r}) F(\vec{r})$$



First experimental evidences

Holm and Meissner (1932)
Bedard and Meissner (1956)
Meissner (1958), (1960)

First theory

De Gennes (1964)
McMillan (1968)
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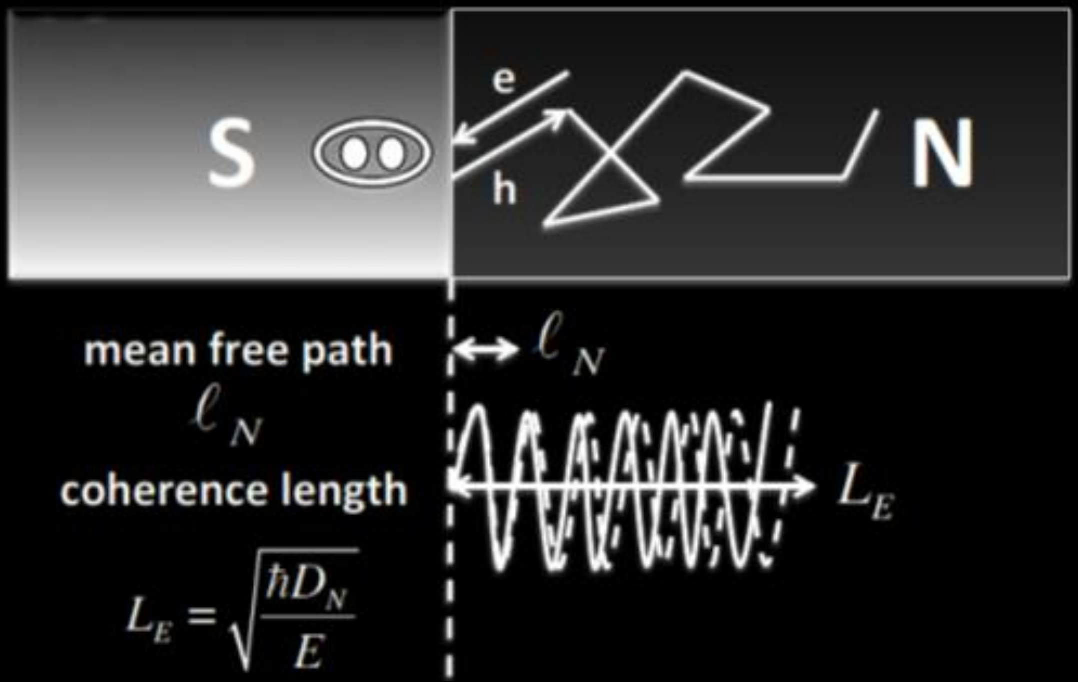
Deutscher and De Gennes (1969)

Modern description of the proximity effect

Andreev reflection at the S/N boundary + extended phase coherence in N

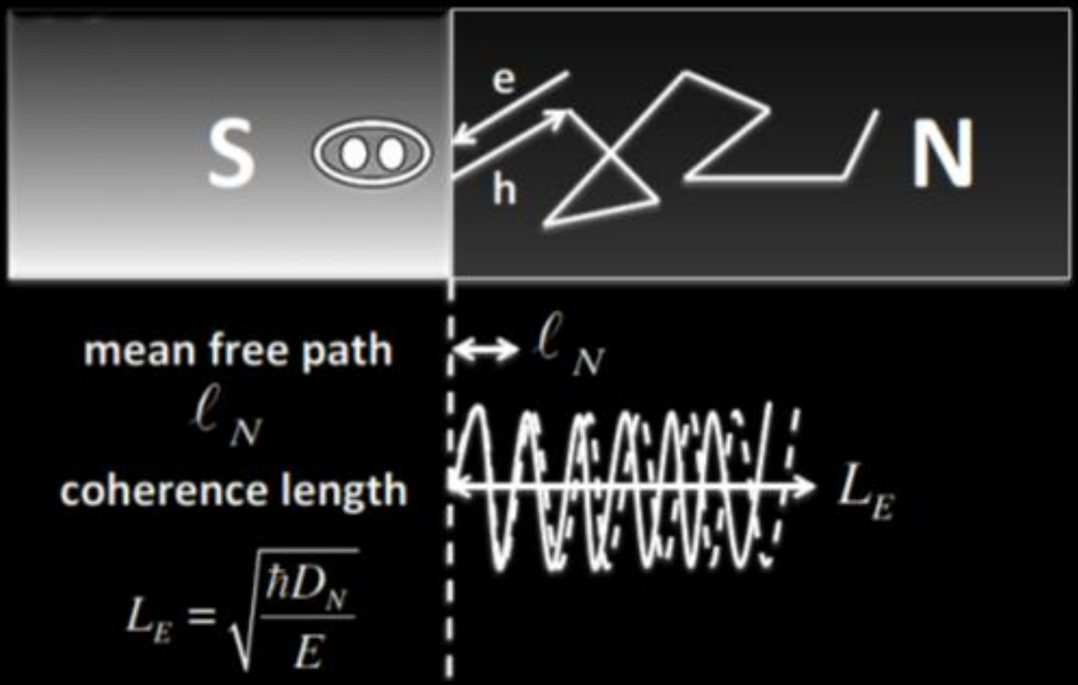


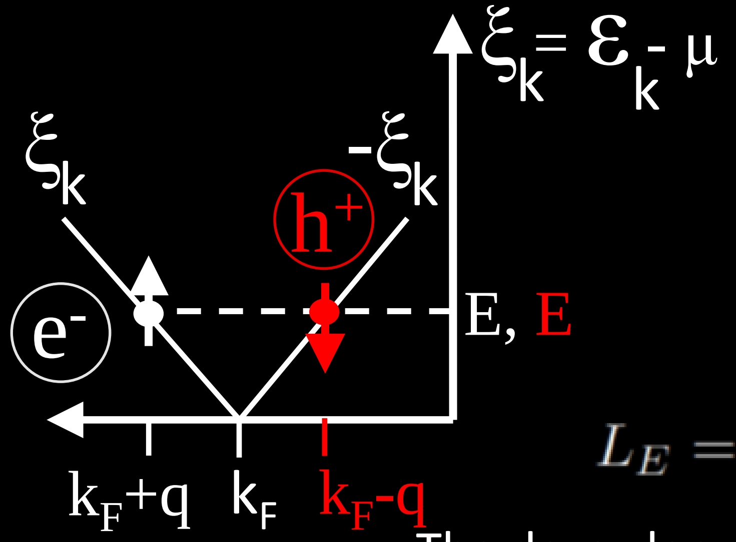
Andreev (1964),
Eilenberger (1968),
Usadel (1970),
Eliashberg (1971)

Larkin *et al.* (1968,75,77),
Schmid & Schön (1975),
Blonder *et al.* (1982),
Zaitsev (1984)

Modern description of the proximity effect

Andreev reflection at the S/N boundary + extended phase coherence in N





$$\Delta\phi = 2Et/\hbar$$

$$t_D = \hbar/E$$

$$L_E = \sqrt{Dt_D} = \sqrt{\hbar D/E}$$

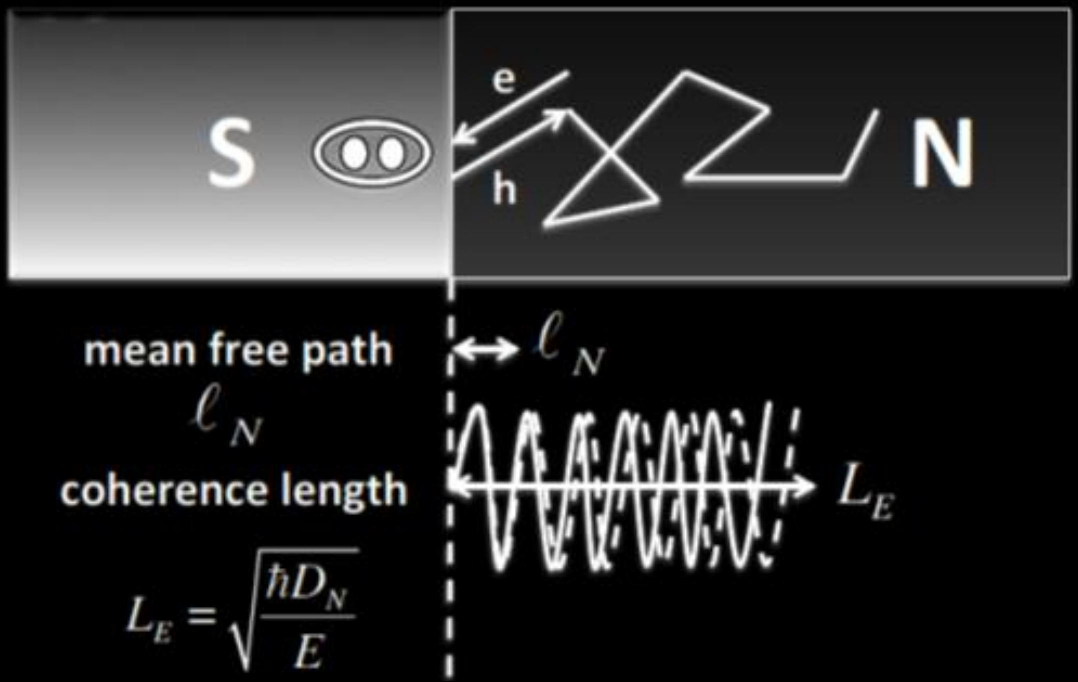
The decay length of pair correlations depends on the energy

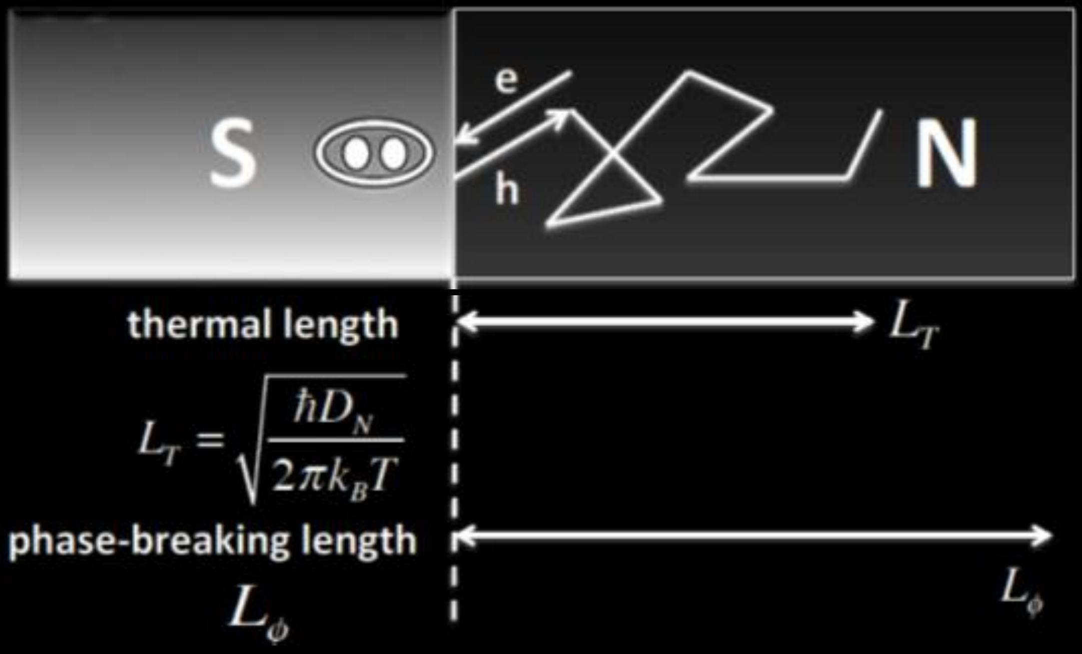
Andreev (1964),
Eilenberger (1968),
Usadel (1970),
Eliashberg (1971)

Larkin *et al.* (1968,75,77),
Schmid & Schön (1975),
Blonder *et al.* (1982),
Zaitsev (1984)

Modern description of the proximity effect

Andreev reflection at the S/N boundary + extended phase coherence in N





Andreev (1964),
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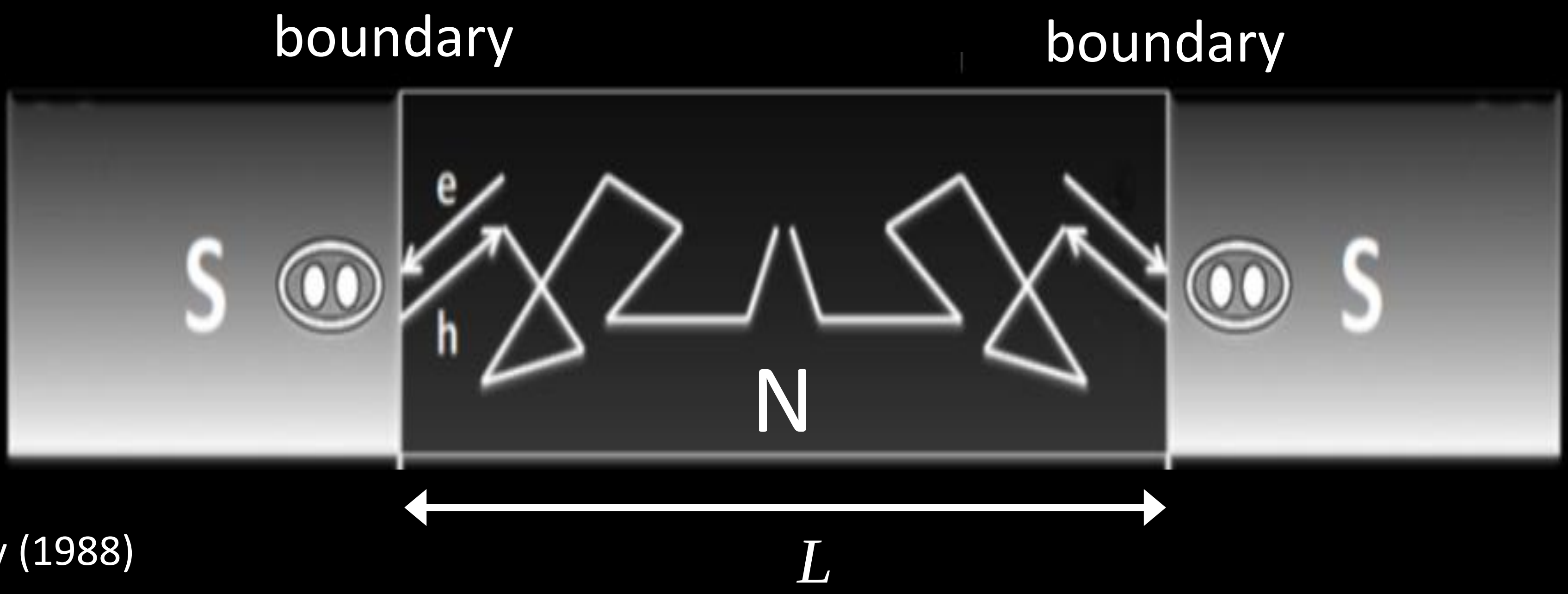
Larkin *et al.* (1968,75,77),
Schmid & Schön (1975),
Blonder *et al.* (1982),
Zaitsev (1984)

Proximity effect for S-N-S connection



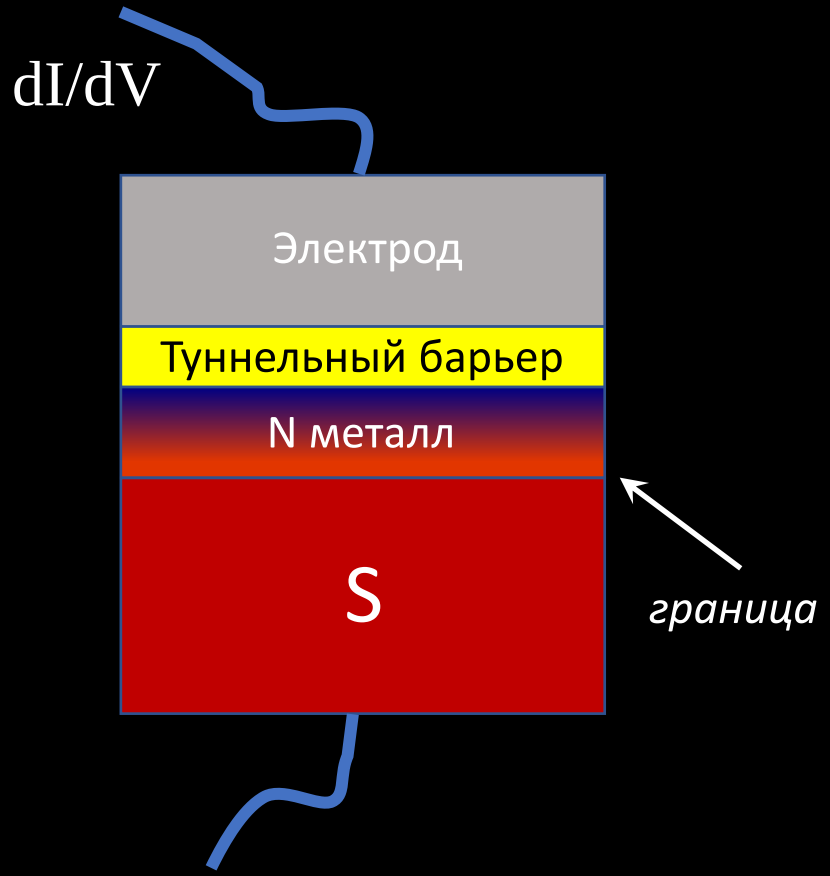
Golubov & Kupriyanov (1988)
Zhou *et al.* (1998)

$$L_E > L \;\Leftrightarrow\; E < E_{\mathrm{Th}} = \hbar D_N / L^2$$

Superconducting correlations propagate for $E < E_{Th}$
minigap Δ_g connected with E_{Th}

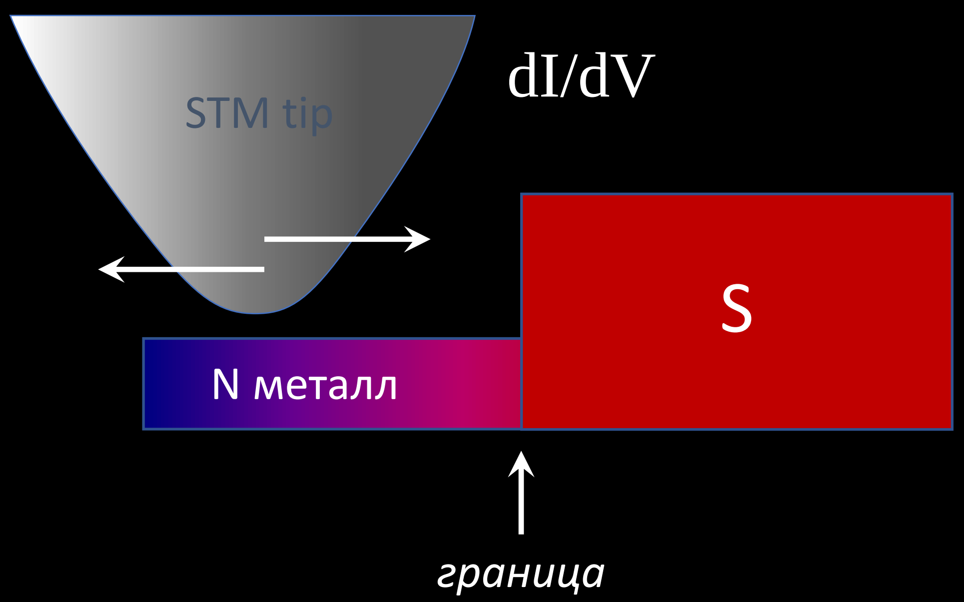
Tunneling as a way to study the proximity effect

Lithographic technologies
Fixed tunnel contact



Development: Direct information on the spatial evolution of the density of states

Сканирующий туннельный зонд



Tunneling spectroscopy of superconductors

157003 (2013) PHYSICAL REVIEW LETTERS week ending 12 APRIL 2013

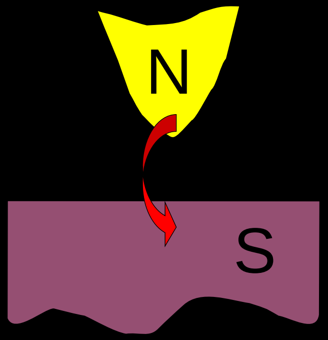
Scanning Tunneling Spectroscopy Study of the Proximity Effect in a Disordered Two-Dimensional Metal

L. Serrier-Garcia,[1] J. C. Cuevas,[2] T. Cren,[1,*] C. Brun,[1] V. Cherkez,[1] F. Debontridder,[1] D. Fokin,[1,3] F. S. Bergeret,[4] and D. Roditchev[1]

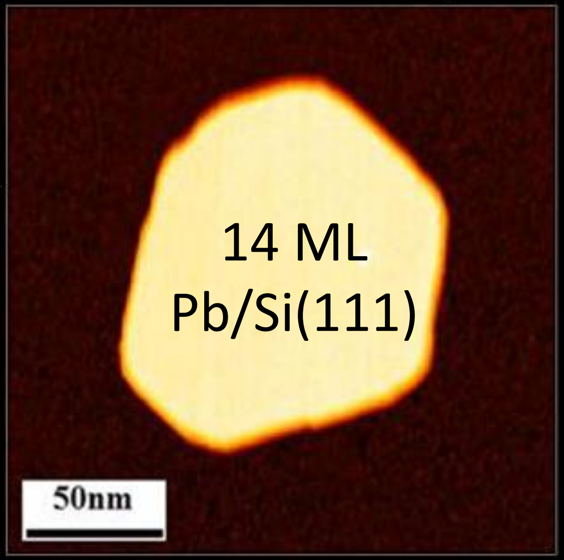
[1]Institut des Nanosciences de Paris, Université Pierre et Marie Curie (UPMC) and CNRS-UMR 7588, 4 place Jussieu, 75252 Paris, France

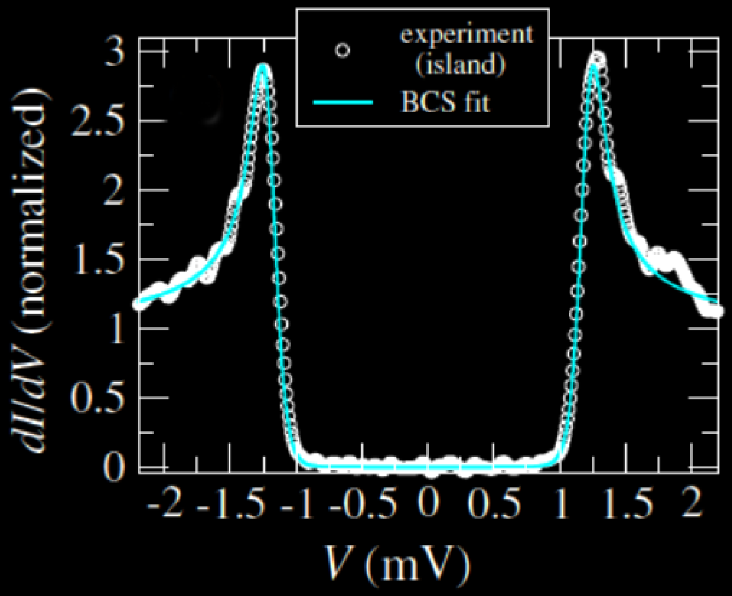
$$dI/dV(\mathbf{r}) = \int_{-\infty}^{\infty} N_s(E,\mathbf{r}) \left[\frac{-\partial f(E+eV)}{\partial(eV)} \right] dE$$

Convolution



BSC DOS $N_S(E) = N_N(E) \frac{E}{\sqrt{E^2 - \Delta^2}}$





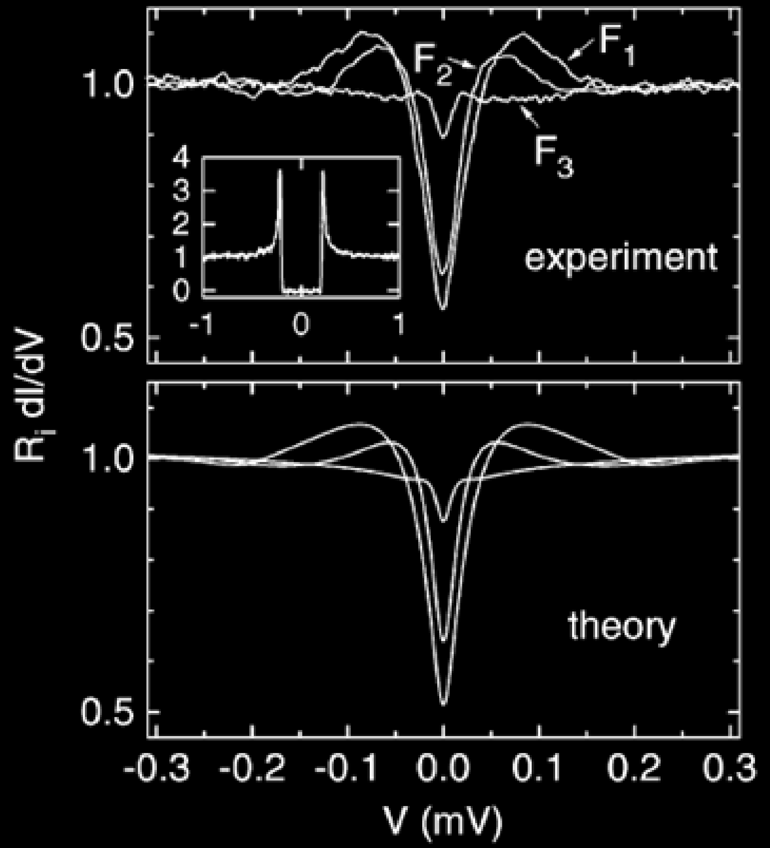
$\Delta = 1.20$ meV $T_{eff} = 0.38$K

Proximity effect in devises

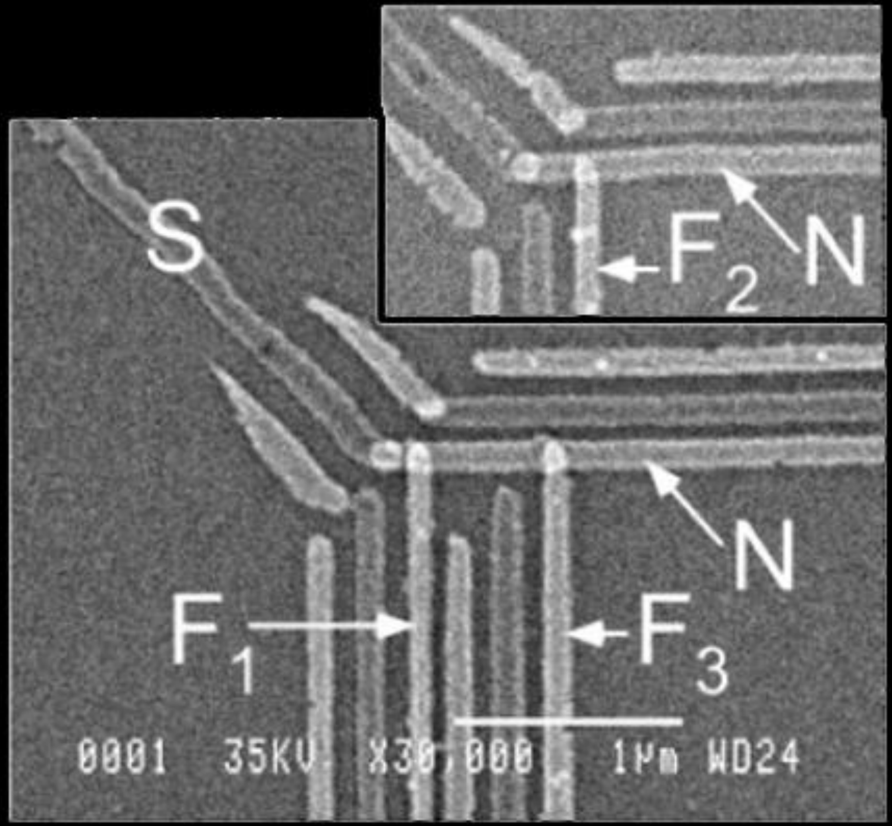
VOLUME 77, NUMBER 14 PHYSICAL REVIEW LETTERS 30 SEPTEMBER 1996

Superconducting Proximity Effect Probed on a Mesoscopic Length Scale

S. Guéron, H. Pothier, Norman O. Birge,* D. Esteve, and M. H. Devoret
Service de Physique de l'Etat Condensé, Commissariat à l'Energie Atomique, Saclay, F-91191 Gif-sur-Yvette Cedex, France
(Received 12 April 1996)



First Study of Spatial Dependency: Nanolithography

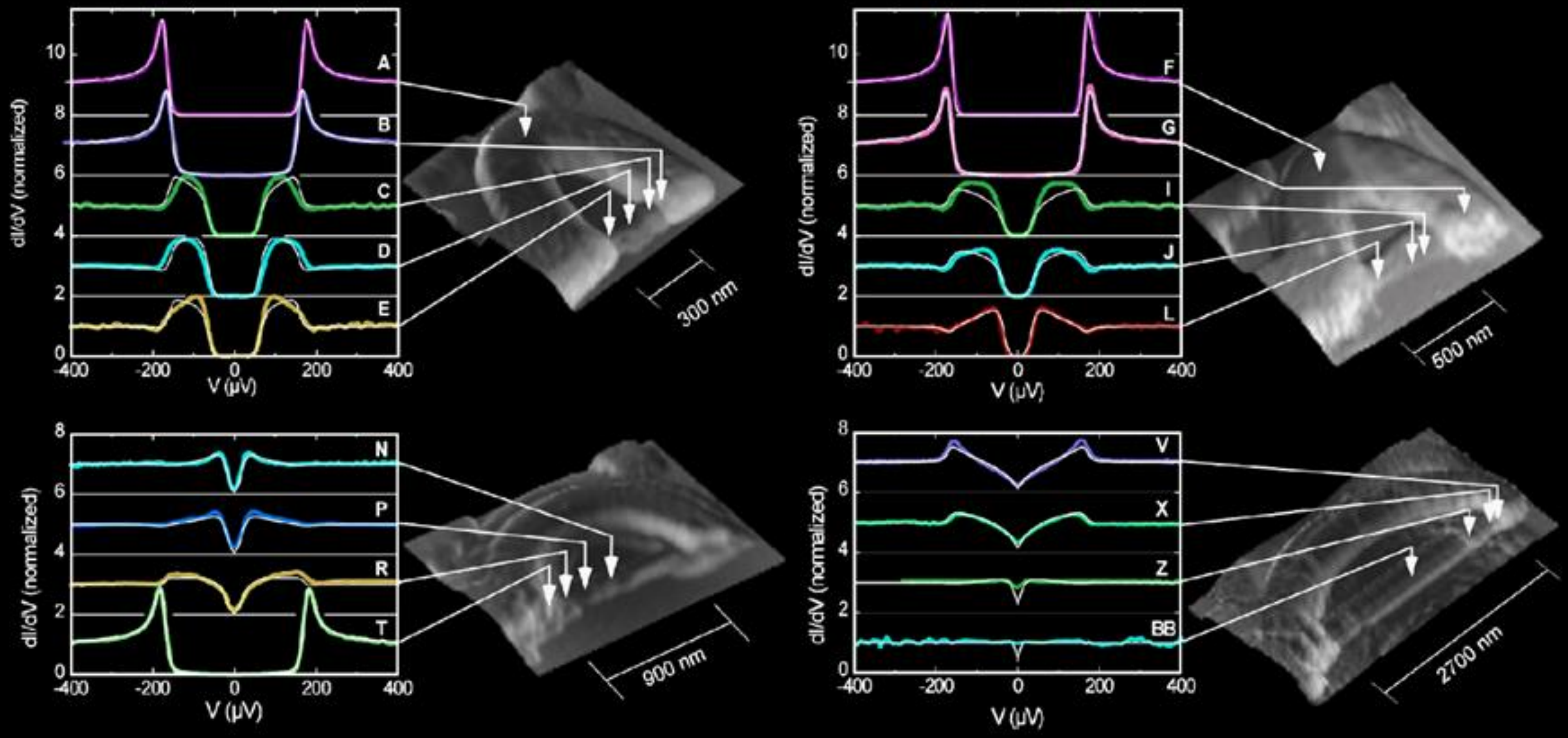


Proximity effect in devises

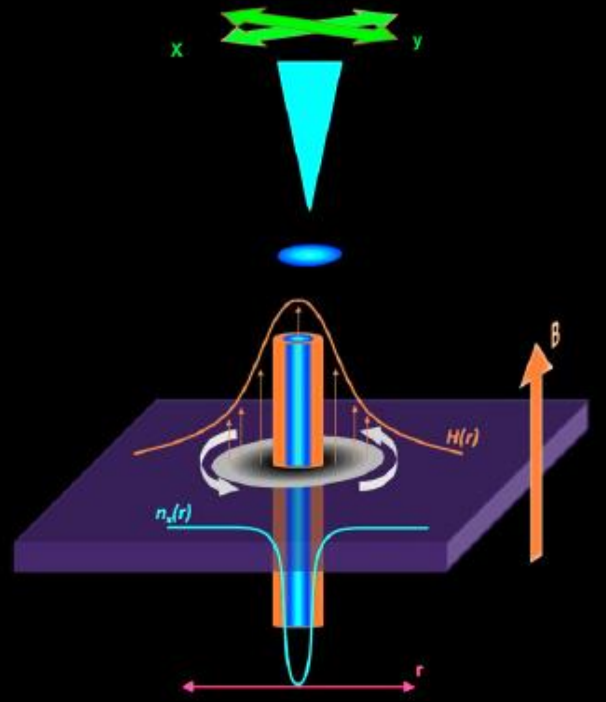
PRL 100, 197002 (2008) PHYSICAL REVIEW LETTERS week ending 16 MAY 2008

Phase Controlled Superconducting Proximity Effect Probed by Tunneling Spectroscopy

H. le Sueur, P. Joyez, H. Pothier, C. Urbina, and D. Esteve



Flux quantization by a superconductor



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Superconductor Science and Technology
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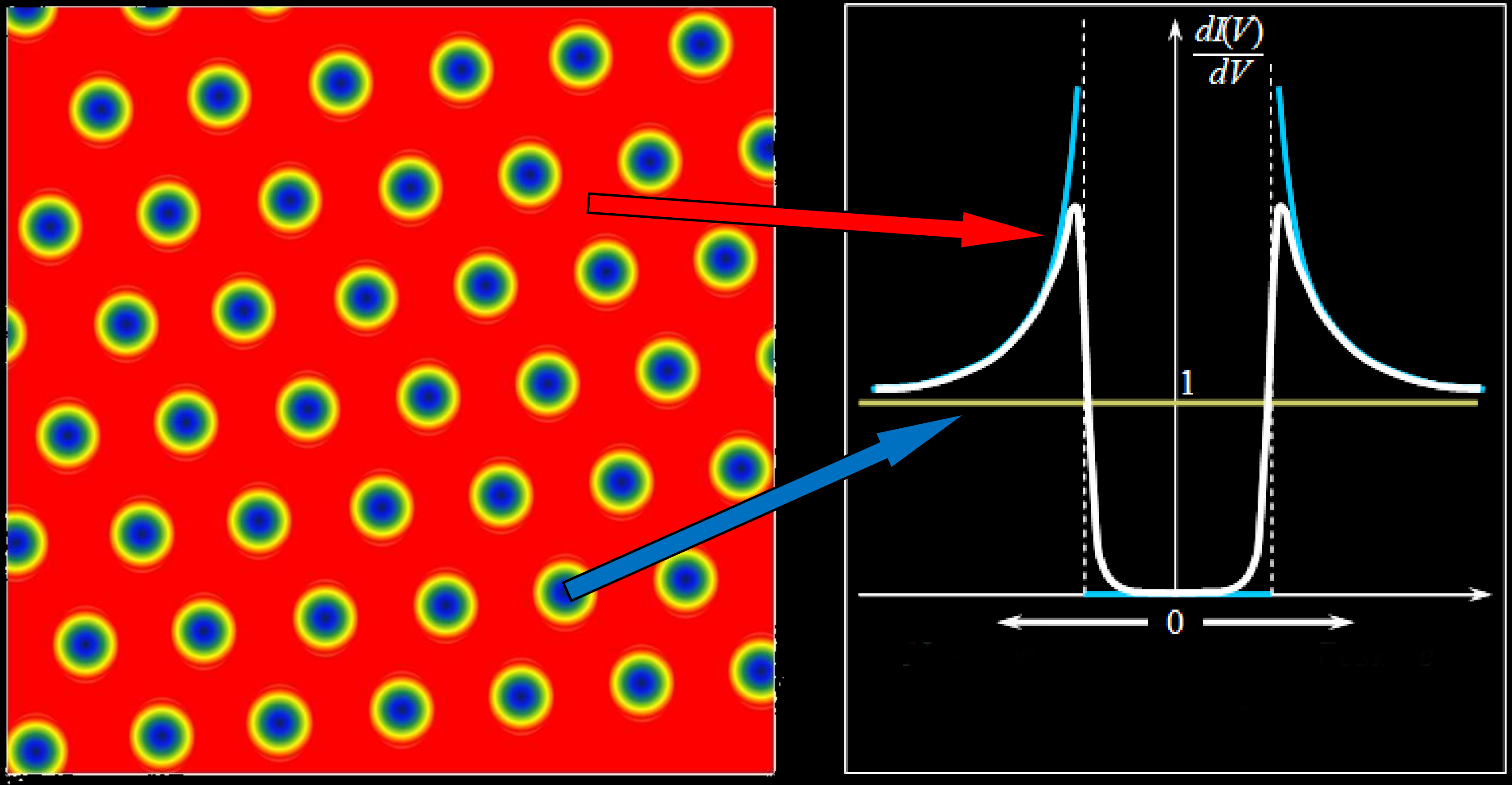
doi:10.1088/0953-2048/27/6/063001

Topical Review

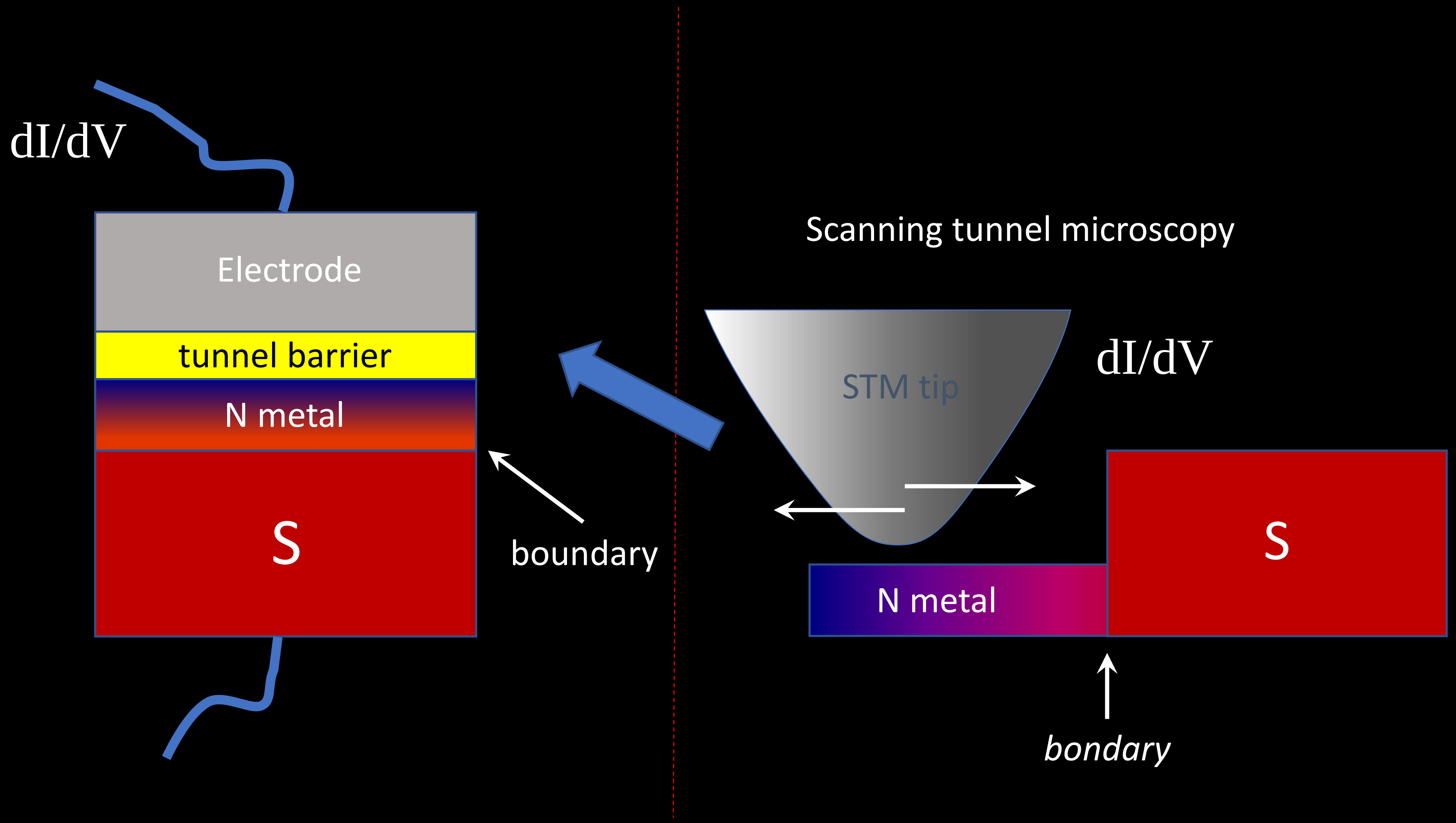
Imaging superconducting vortex cores and lattices with a scanning tunneling microscope

H Suderow[1,2], I Guillamón[1,2,3], J G Rodrigo[1,2] and S Vieira[1,2]

[1] Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain



Proximity effect at the boundary of a superconductor with a nonsuperconducting metal in the diffuse limit



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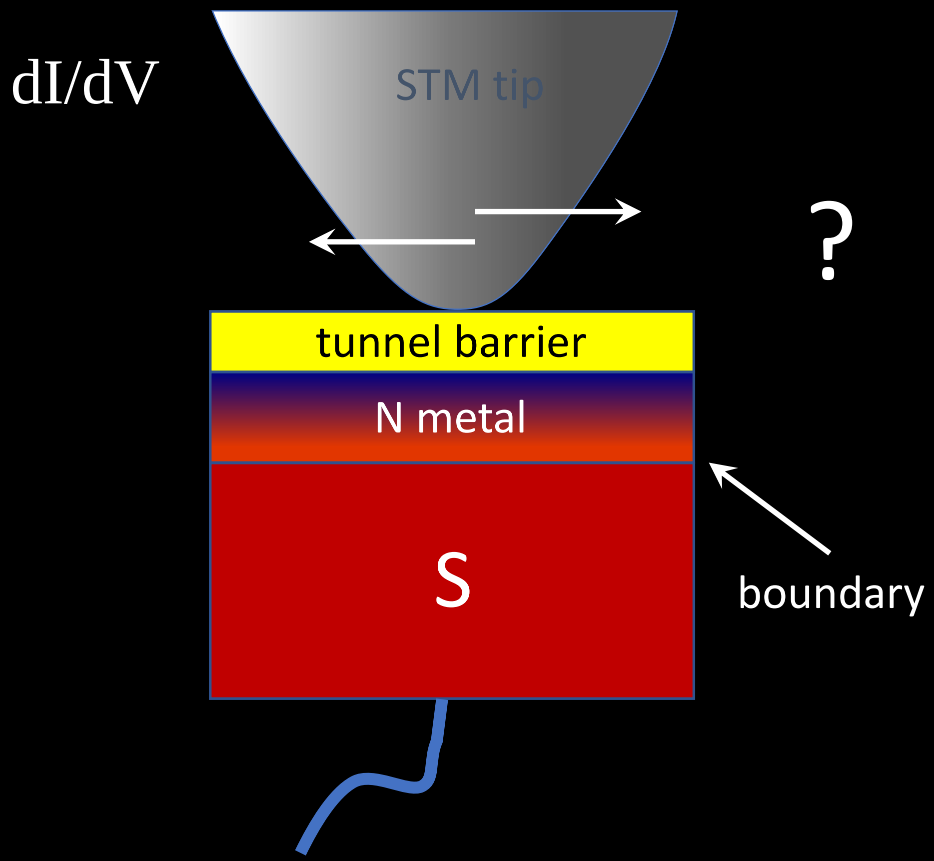

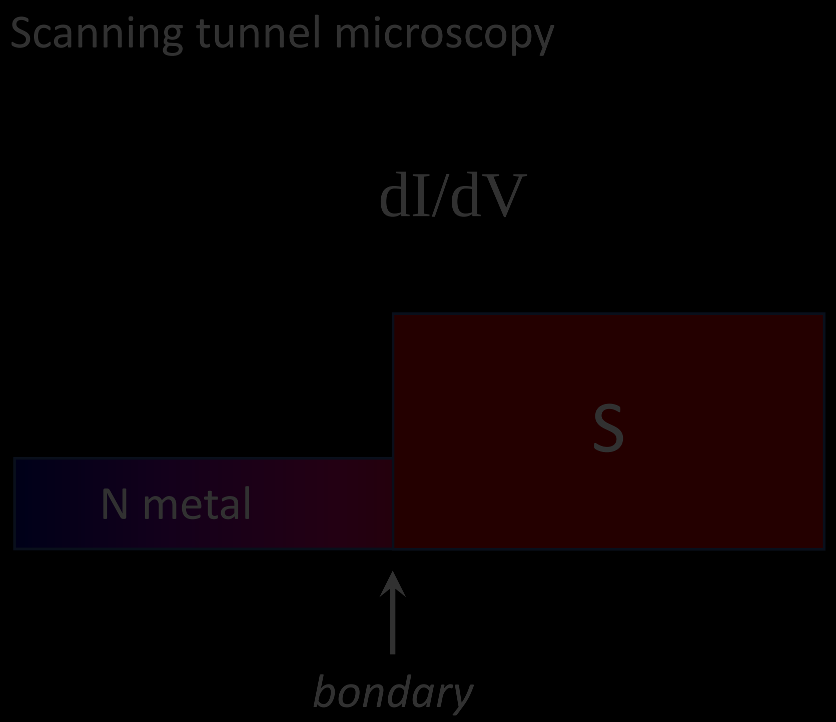

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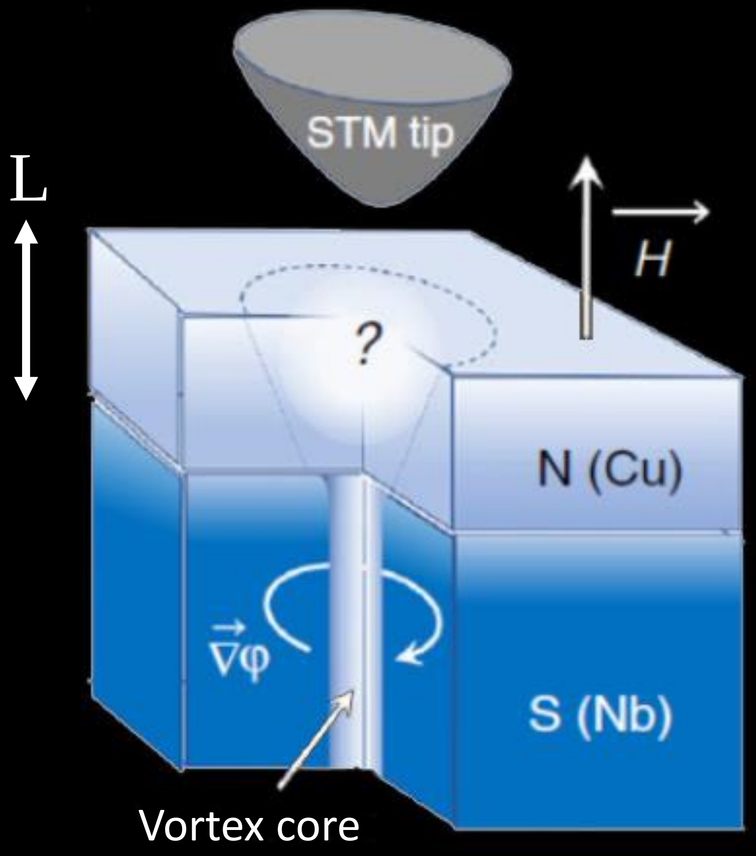


ARTICLE

DOI: 10.1038/s41467-018-04582-1 OPEN

nature COMMUNICATIONS

Expansion of a superconducting vortex core into a diffusive metal

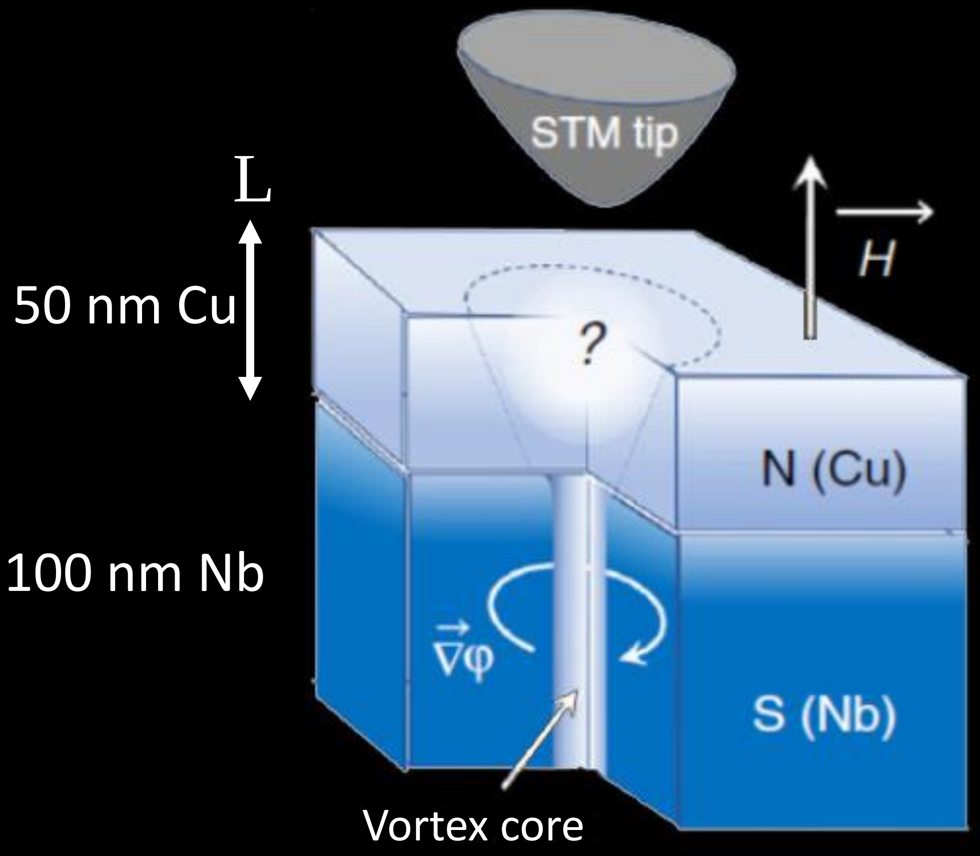
Vasily S. Stolyarov[1,2,3,4,5], Tristan Cren[2], Christophe Brun[2], Igor A. Golovchanskiy[1,5], Olga V. Skryabina[1,3], Daniil I. Kasatonov[1], Mikhail M. Khapaev[1,6,7], Mikhail Yu. Kupriyanov[1,7,8], Alexander A. Golubov[1,9] & Dimitri Roditchev[1,2,10,11]

Vortex size?

3D- proximity effect

minigap Δ, related to $\hbar D_N / L^2$

Proximity effect at the boundary of a superconductor with a nonsuperconducting metal in the diffuse limit



Cu, Nb:

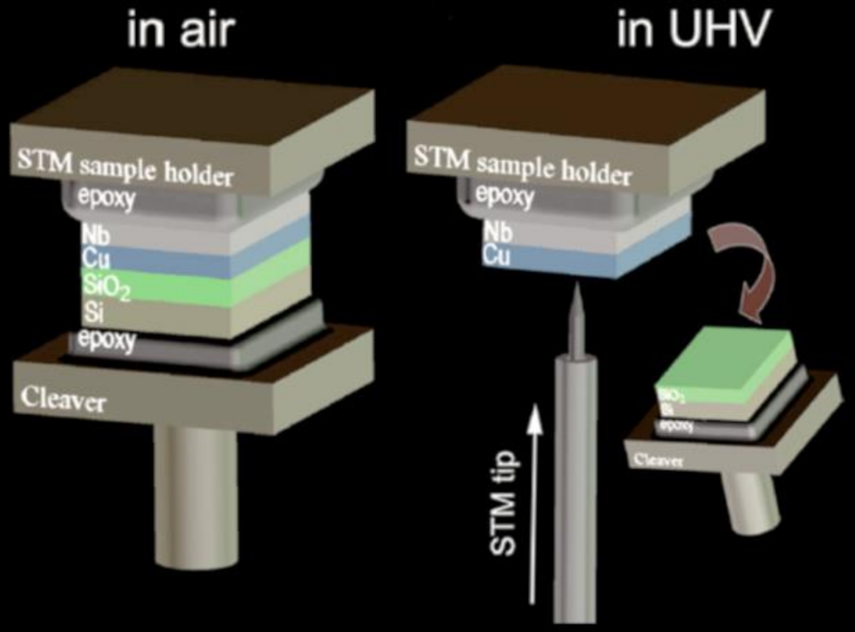
Magnetron sputtering

d_{Nb} = 100 nm

d_{Cu} = 50 nm

d_{SiO2} = 270 nm

d_{Si} = 0.3 mm

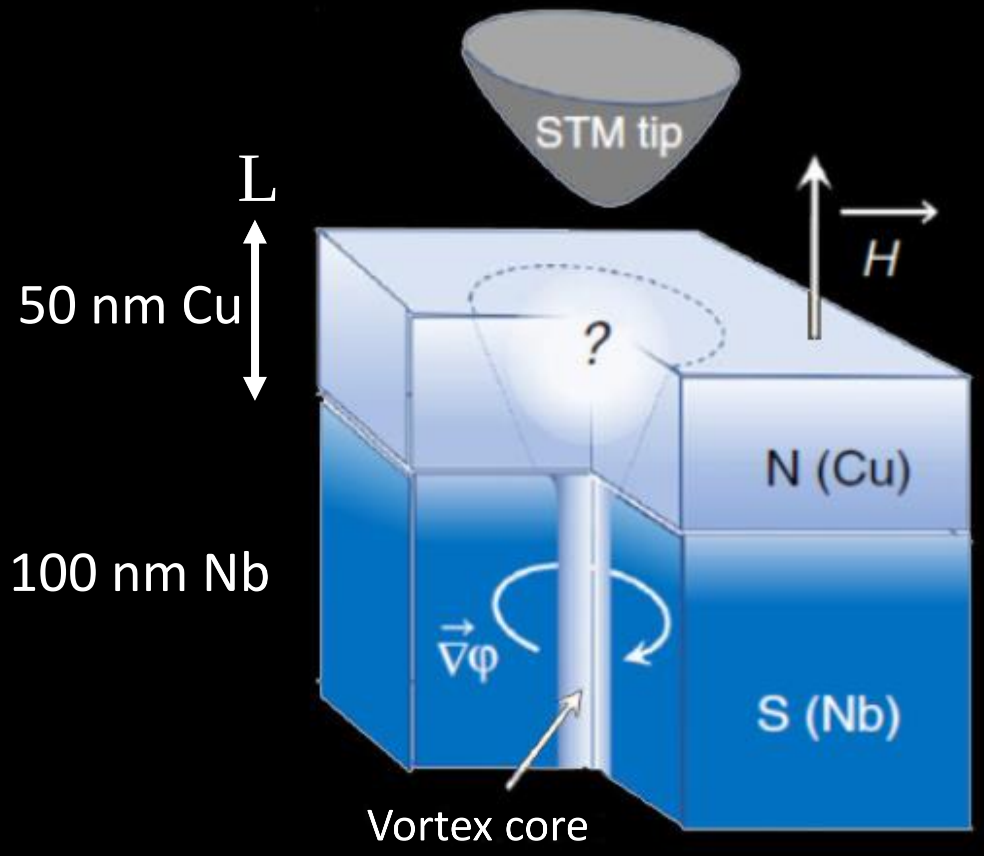


APPLIED PHYSICS LETTERS **104**, 172604 (2014)

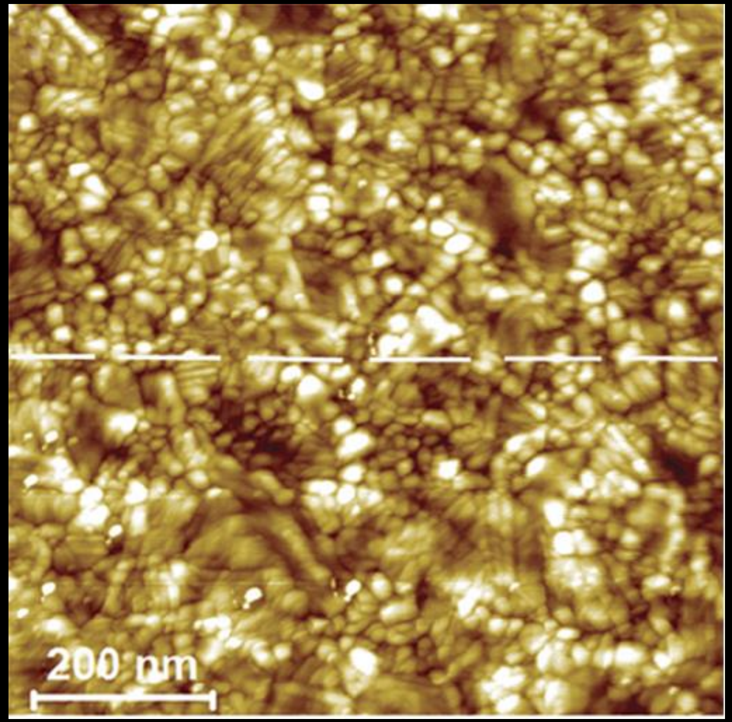
Ex situ **elaborated proximity mesoscopic structures for ultrahigh vacuum scanning tunneling spectroscopy**

V. S. Stolyarov,[1,2,3,4,5,6] T. Cren,[1,2,a)] F. Debontridder,[1,2] C. Brun,[1,2] I. S. Veshchunov,[7,3] O. V. Skryabina,[3] A. Yu. Rusanov,[8] and D. Roditchev[1,2,9]
[1]*UMR 7588, Institut des Nanosciences de Paris, UPMC Univ Paris 06, Sorbonne Universités, F-75005 Paris, France*

Proximity effect at the boundary of a superconductor with a nonsuperconducting metal in the diffuse limit



STM topography



$D_N = \ell_N v_F/3 \approx 100\ cm^2.s^{-1}$

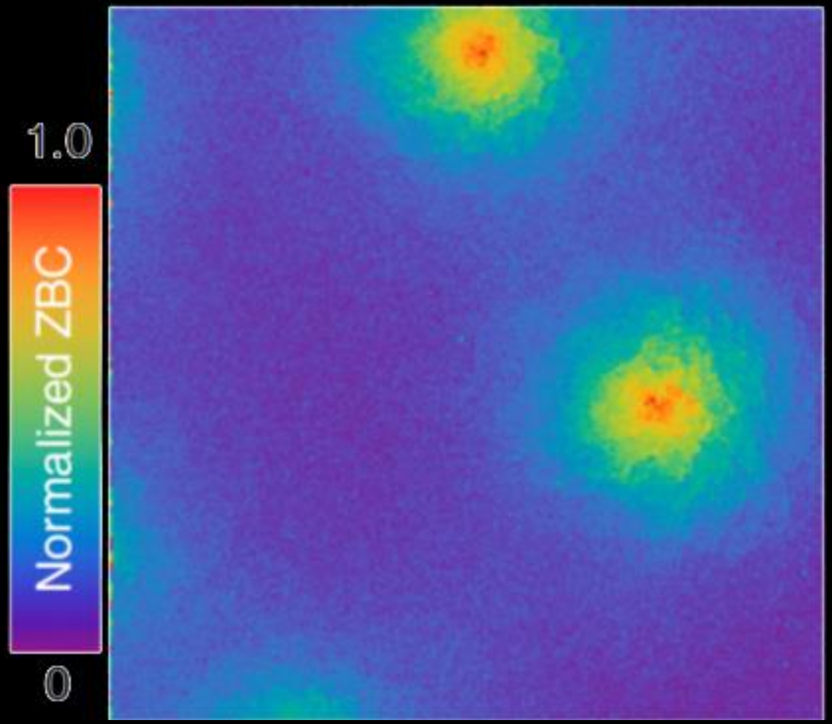
$\xi_N = (\hbar D_N/\Delta)^{1/2} \approx 37$ nm

Grain size ~ ℓ_N ~ 20 nm

Proximity effect at the boundary of a superconductor with a nonsuperconducting metal in the diffuse limit

T=300 mK

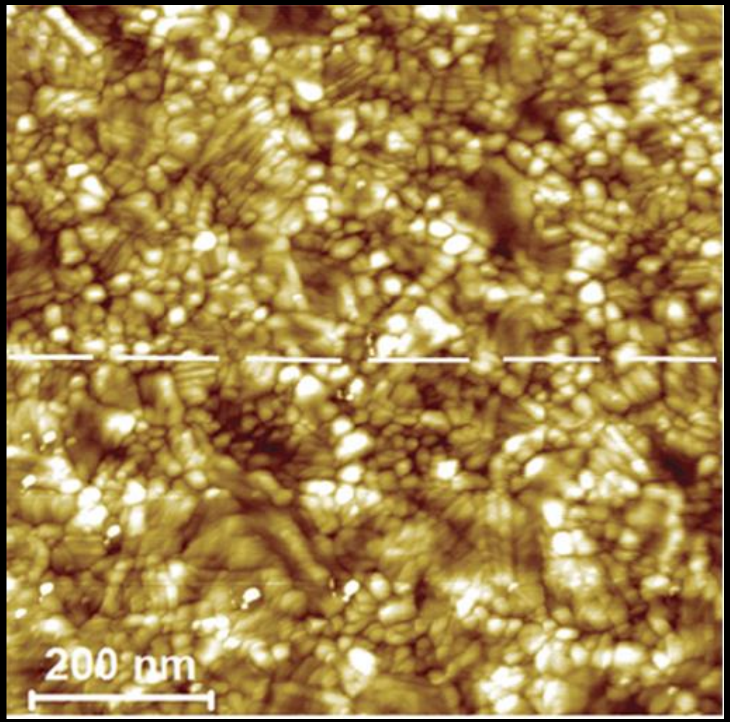
STS map



B = 5 mT

dI/dV(V=0)

STM topography



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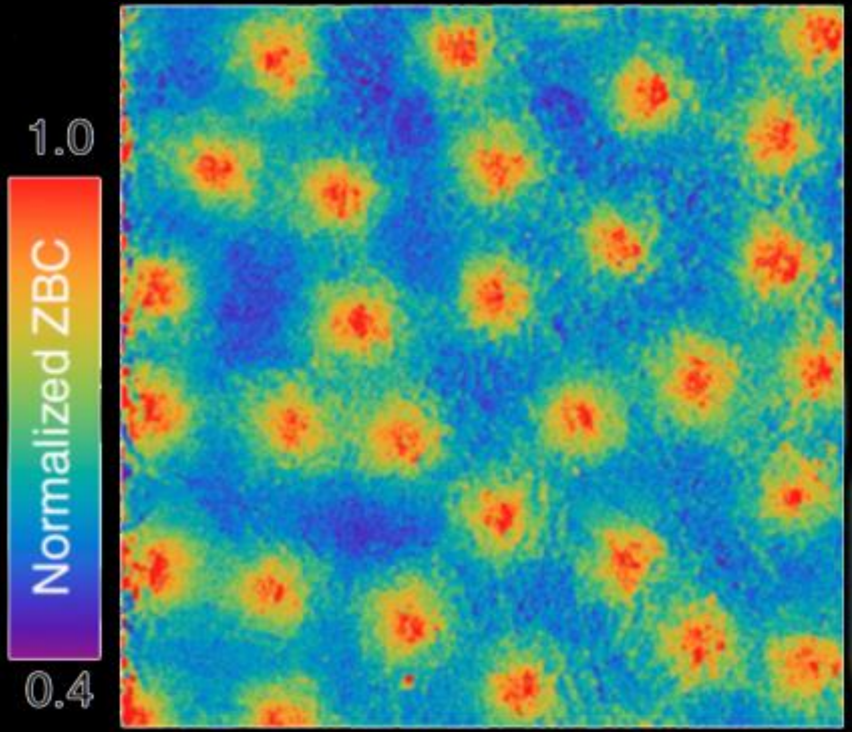
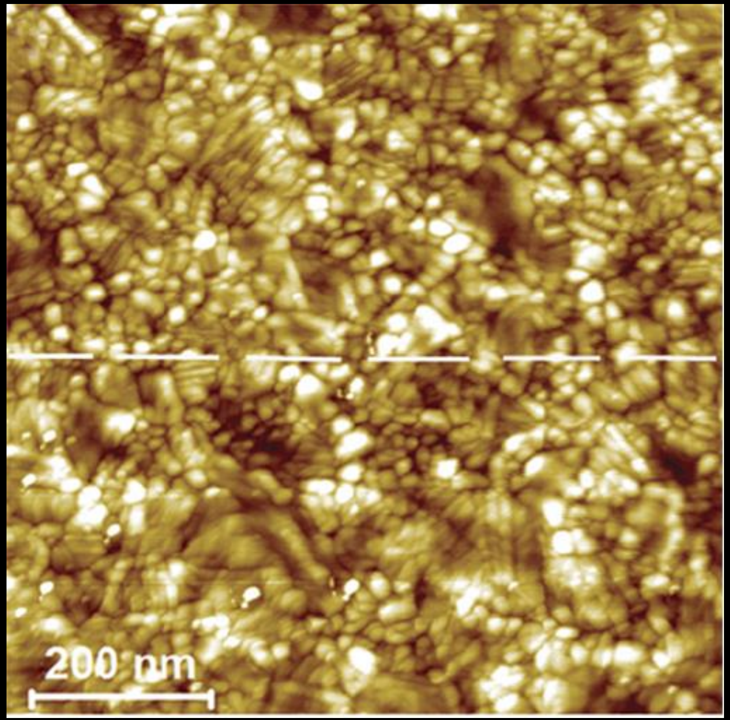
STS map



B = 55 mT
dI/dV(V=0)

T=300 mK

STM topography



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Grain size ~ ℓ_N ~ 20 nm

Proximity effect at the boundary of a superconductor with a nonsuperconducting metal in the diffuse limit

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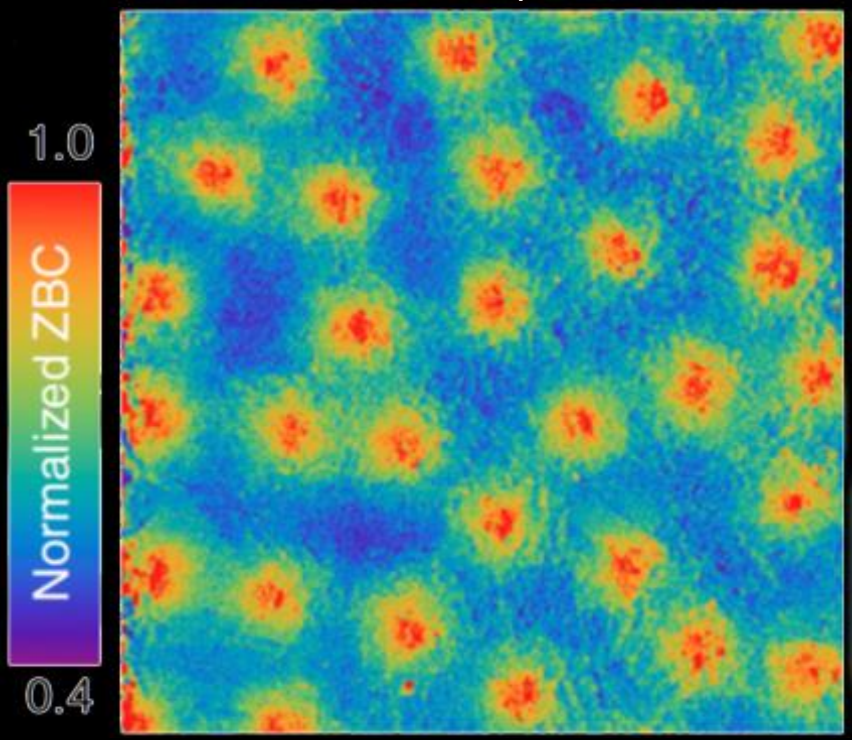
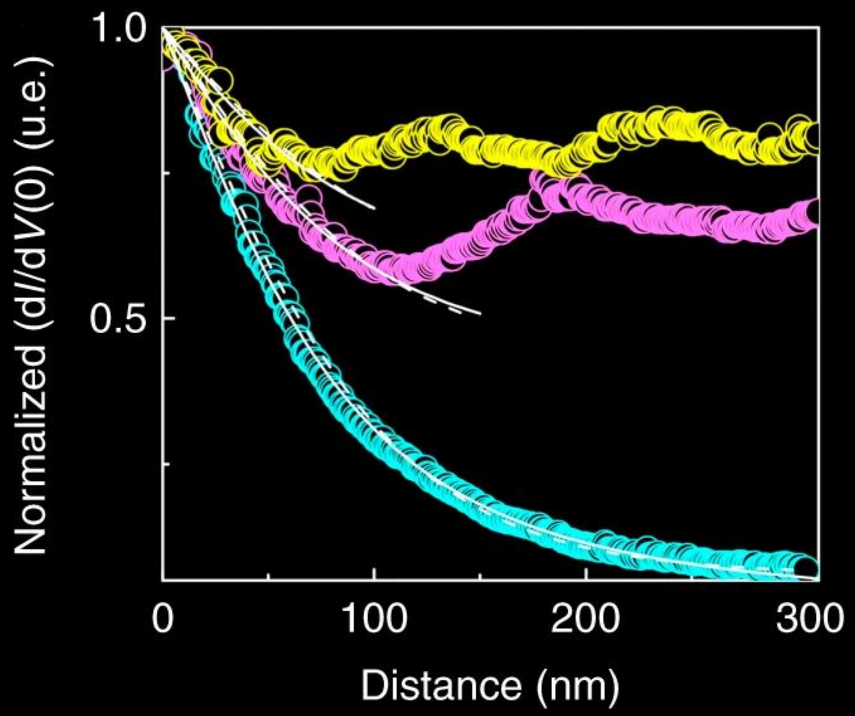


B = 55 mT
dI/dV(V=0)

T=300 mK



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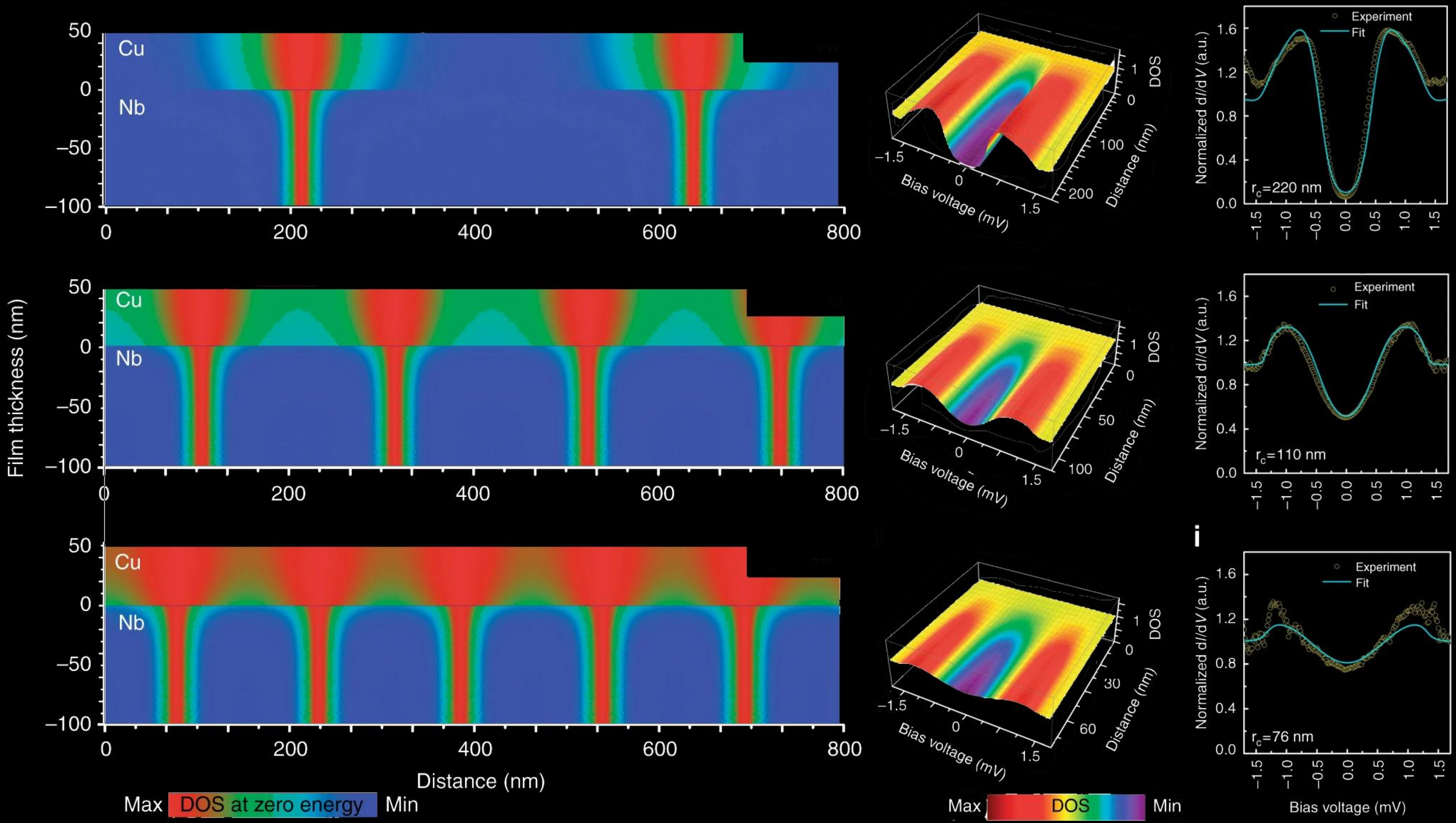
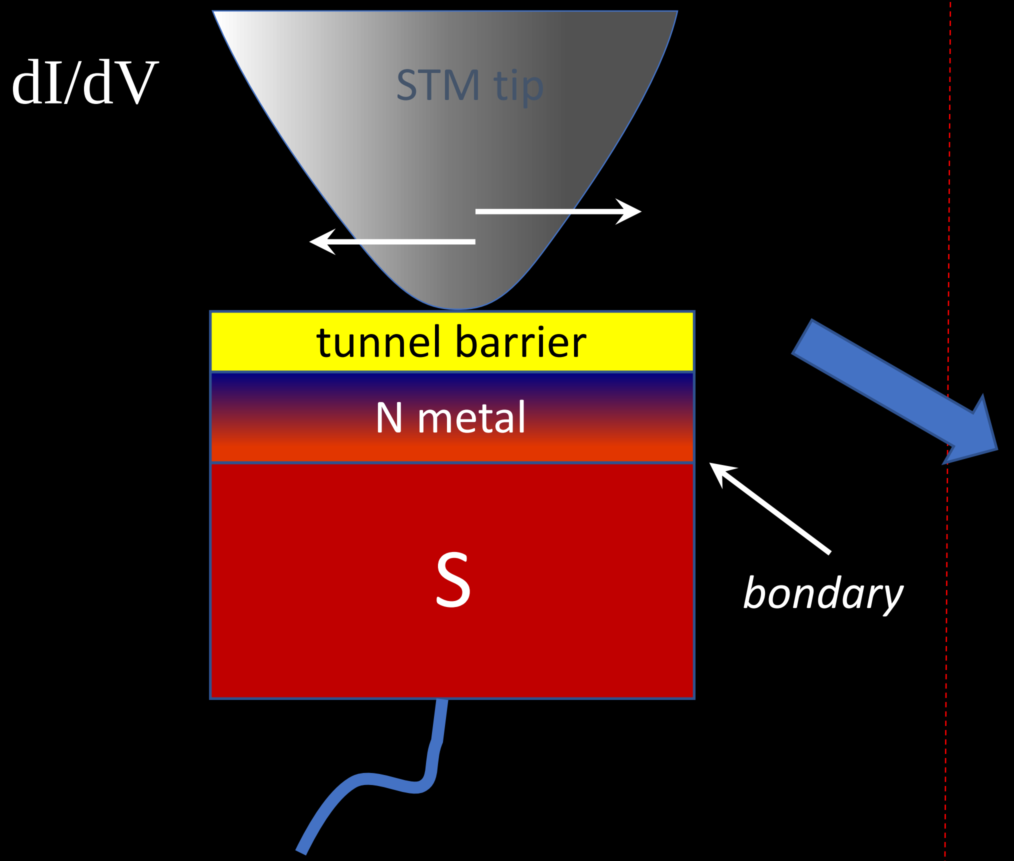
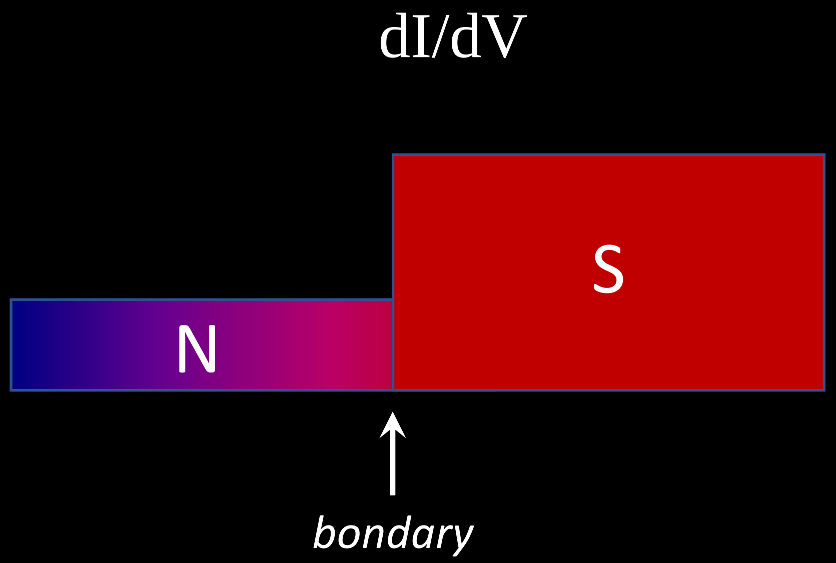


Rb = 150 Ohм

Josephson vortex: direct observation



Scanning tunnel microscopy



Josephson vortex: direct observation

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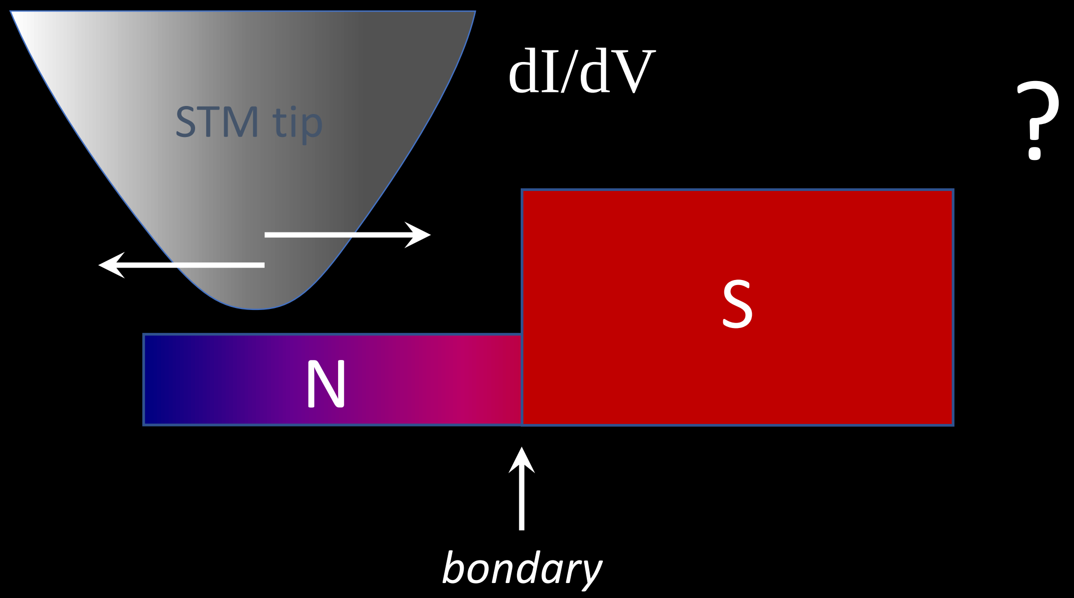
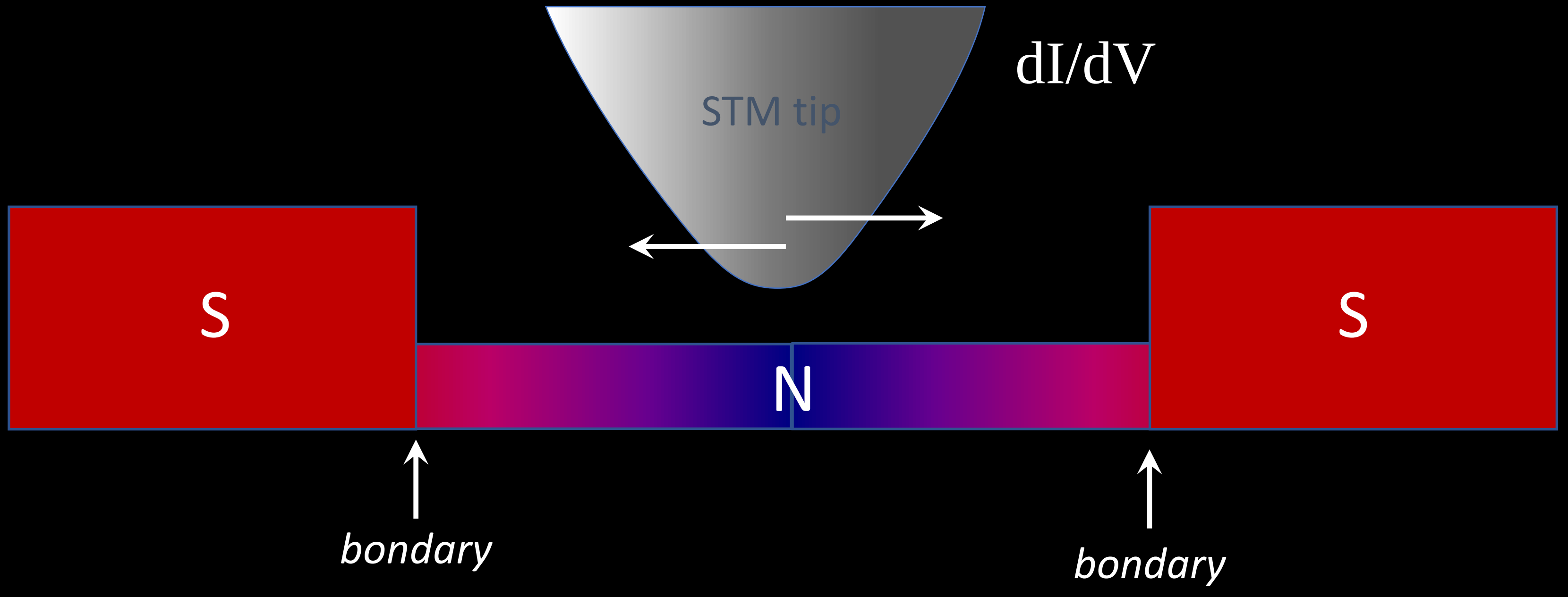


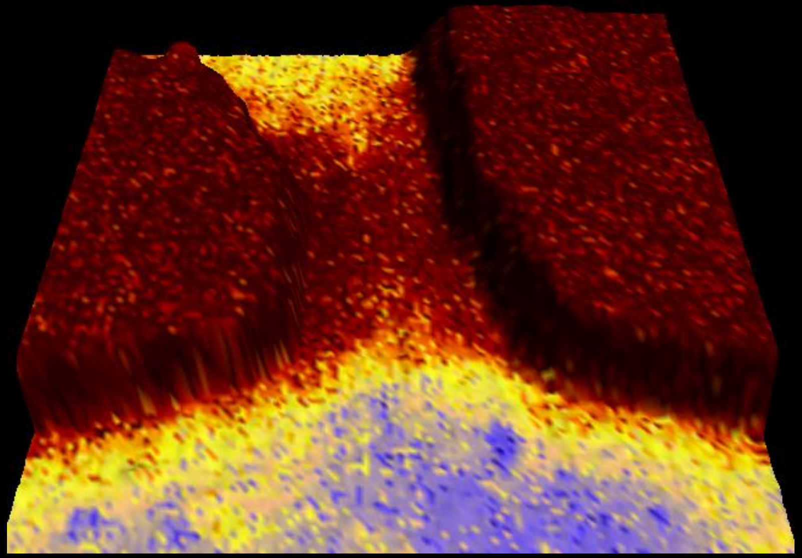
Josephson vortex: direct observation

Scanning tunnel microscopy



Josephson vortex as a logical state of low-dissipative devices

Part 2: **Josephson vortex at SNS**



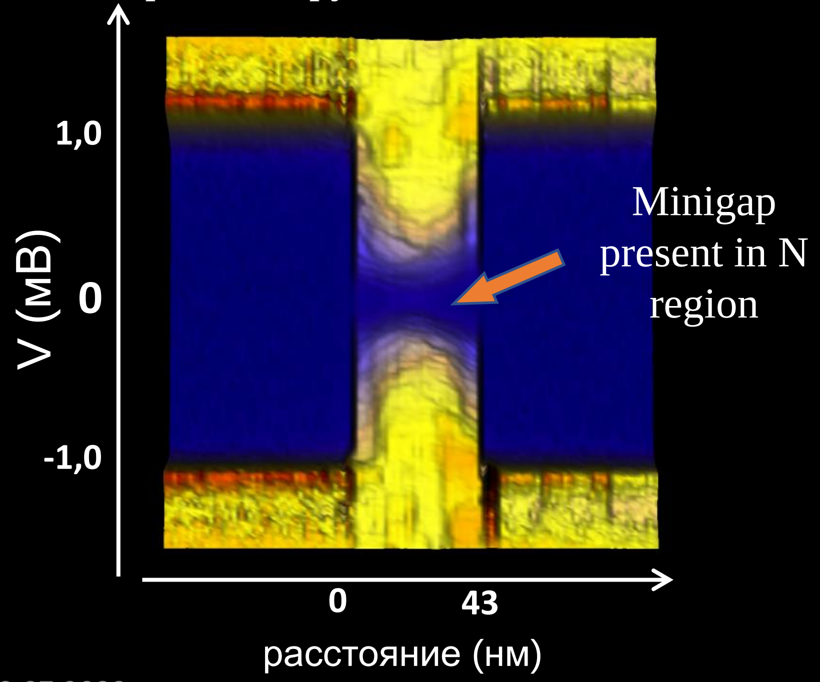
Josephson vortex: direct observation

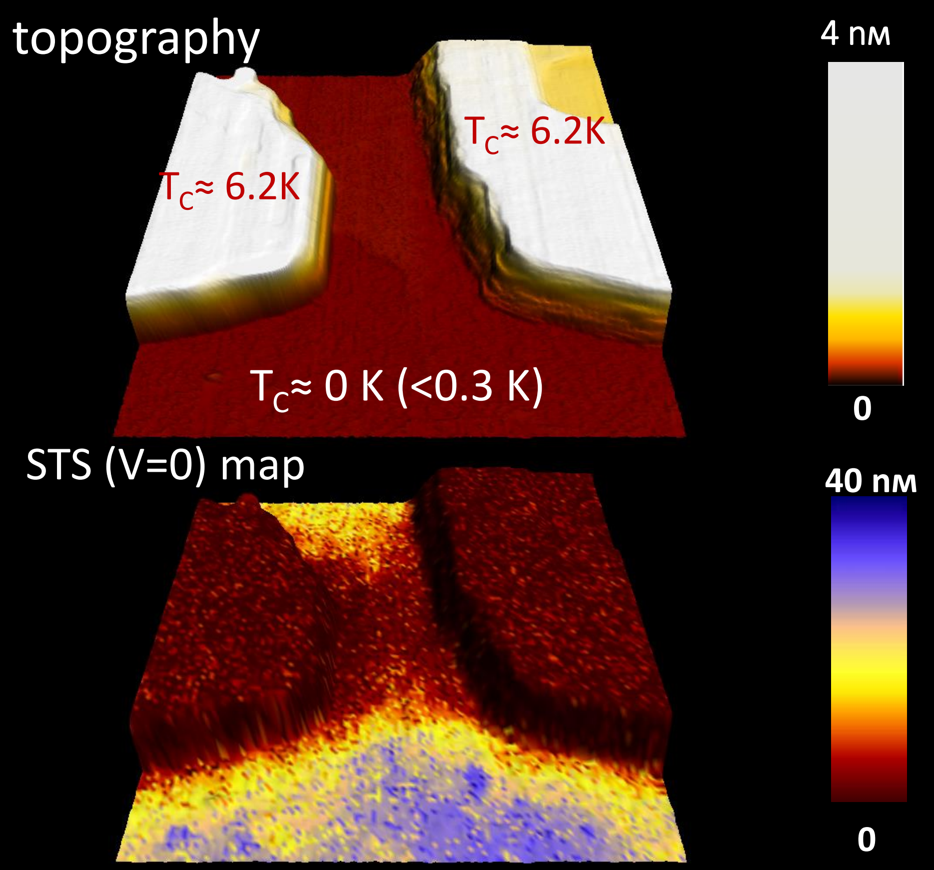
LETTERS
PUBLISHED ONLINE: 23 FEBRUARY 2015 | DOI: 10.1038/NPHYS3240
nature physics

Direct observation of Josephson vortex cores

Dimitri Roditchev[1,2], Christophe Brun[1], Lise Serrier-Garcia[1], Juan Carlos Cuevas[3], Vagner Henrique Loiola Bessa[4], Milorad Vlado Milošević[4,5], François Debontridder[1], Vasily Stolyarov[1] and Tristan Cren[1]*

dI/dV- spectroscopy in linear distribution





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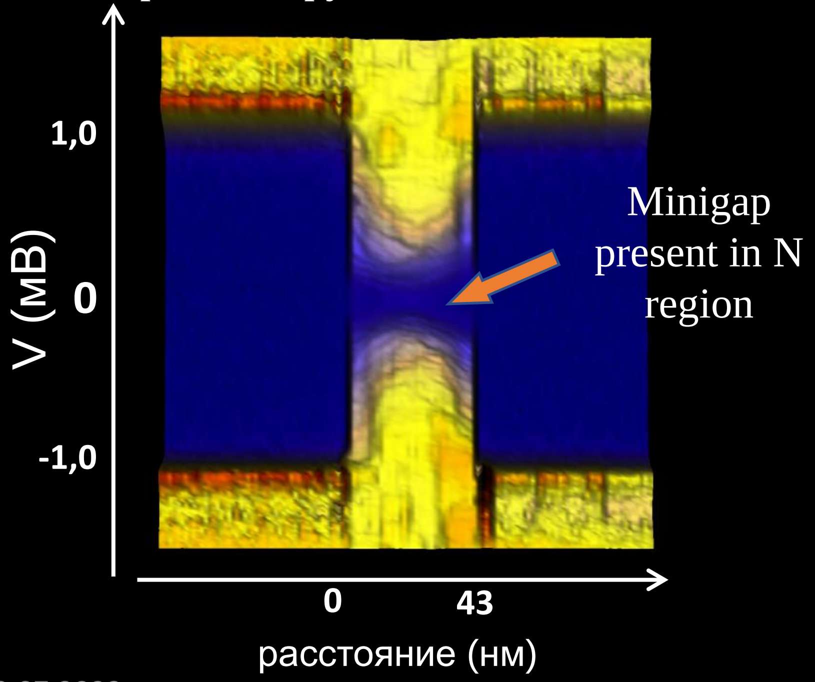

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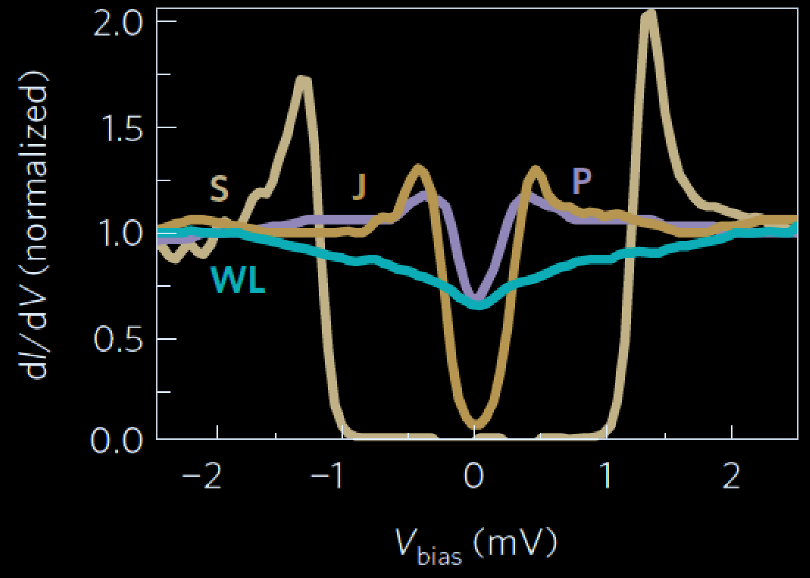

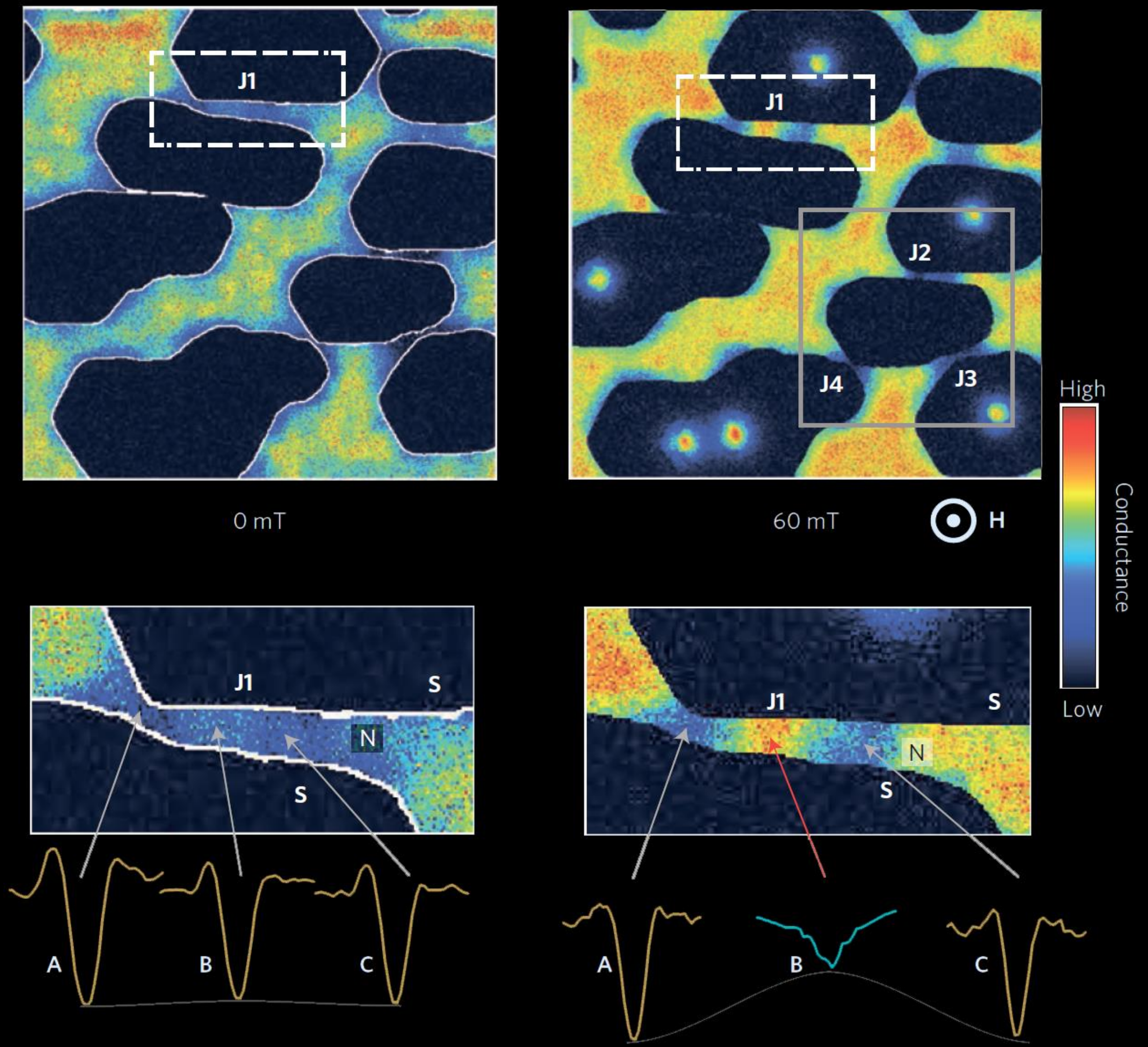

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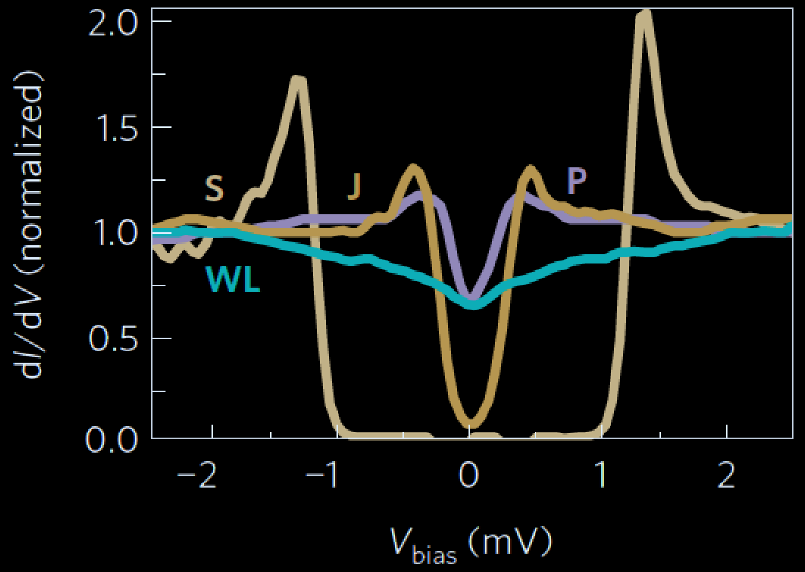
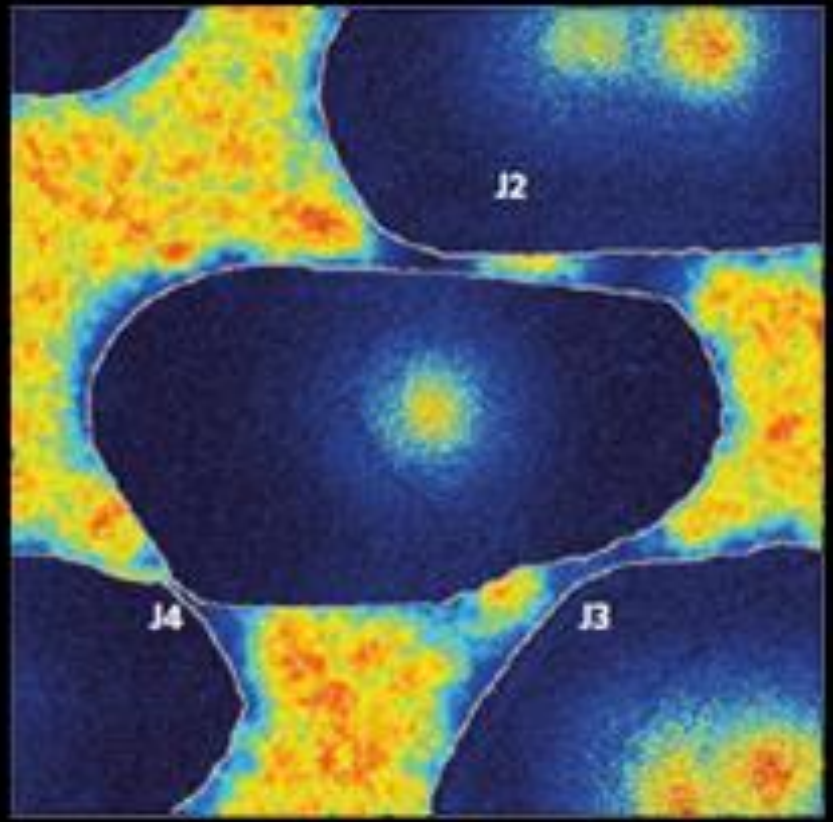


120 mT



Josephson vortex: direct observation

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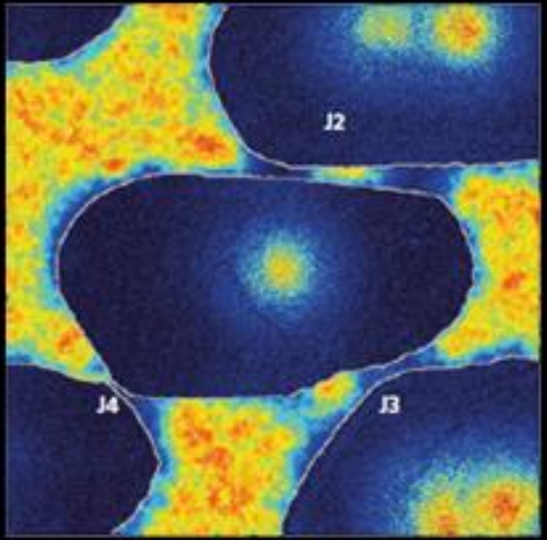
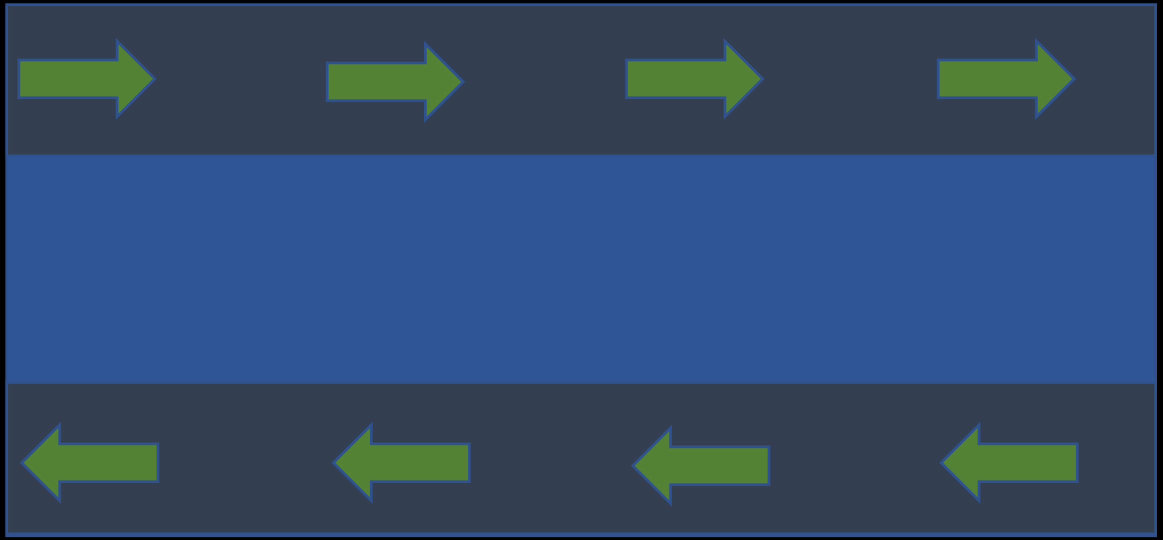
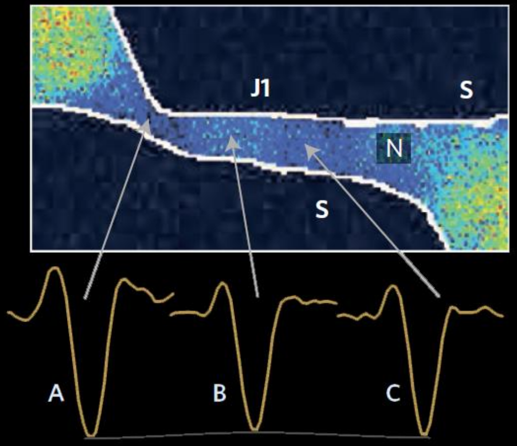
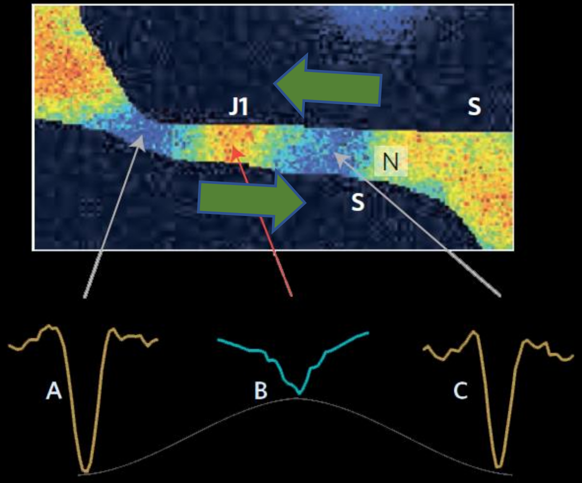
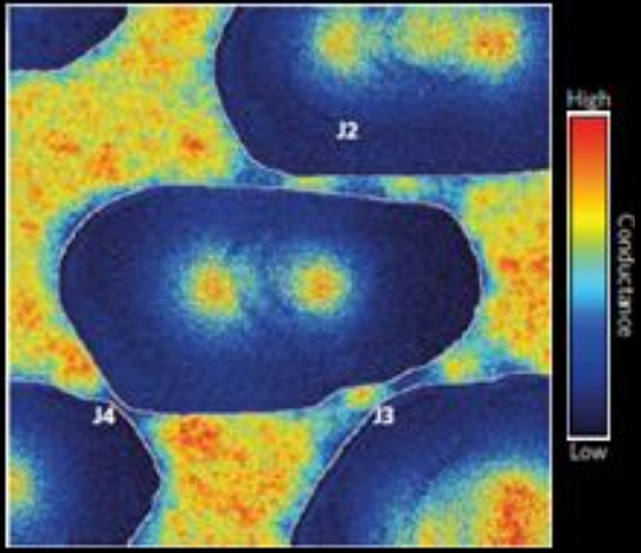






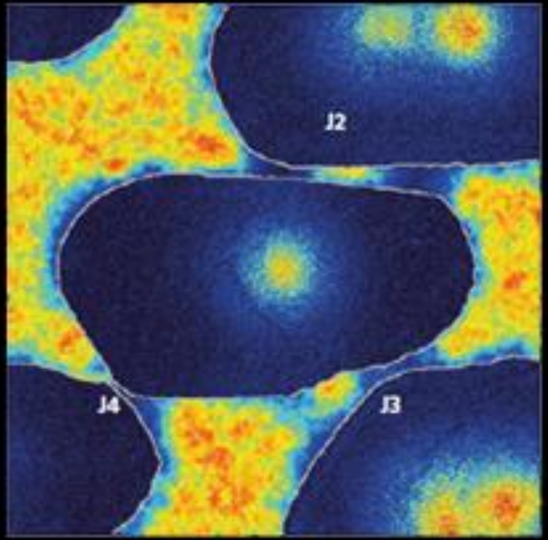


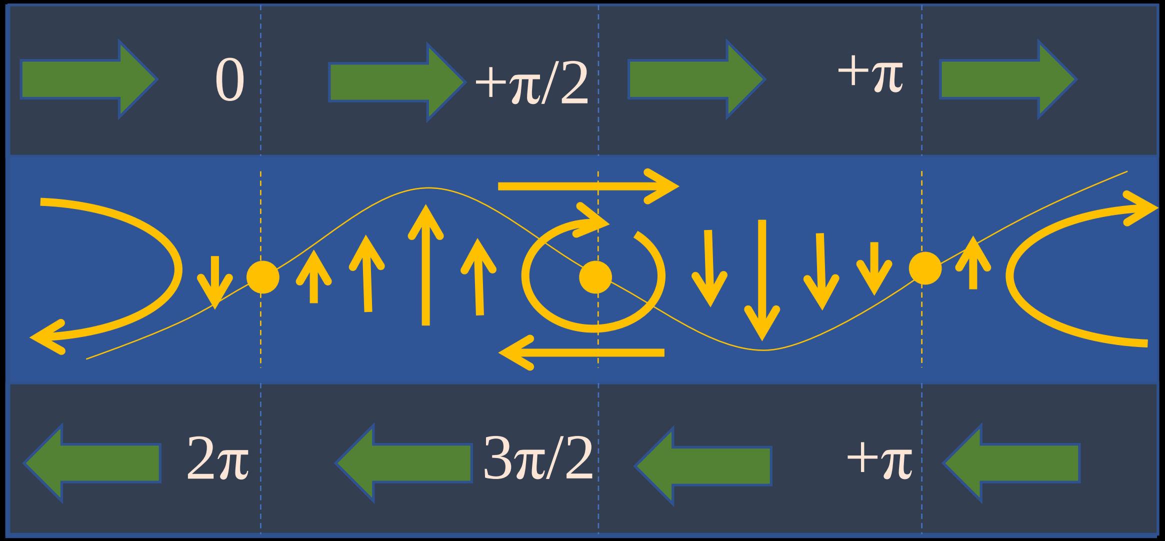
180 mT



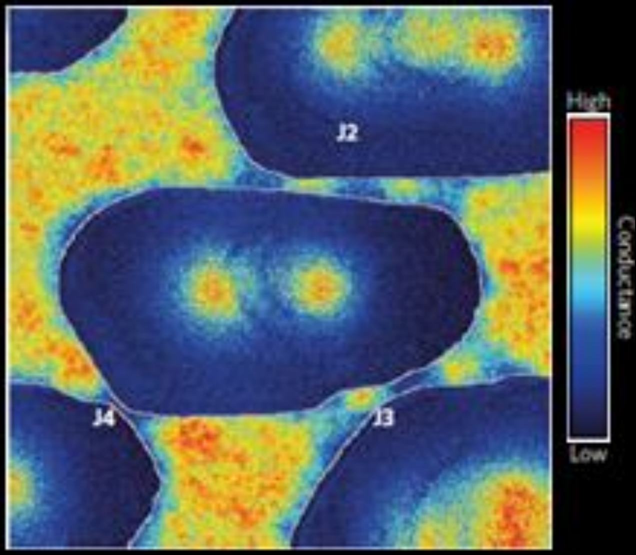
Josephson vortex: direct observation

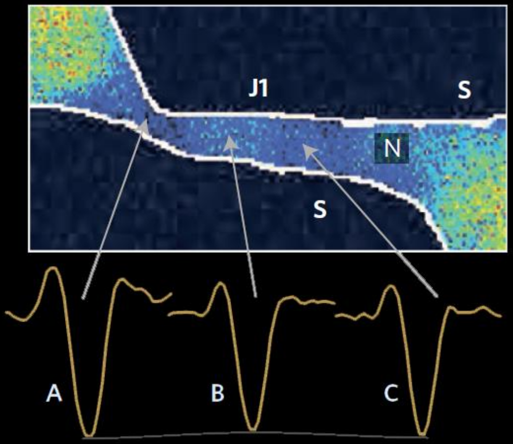
120 mT

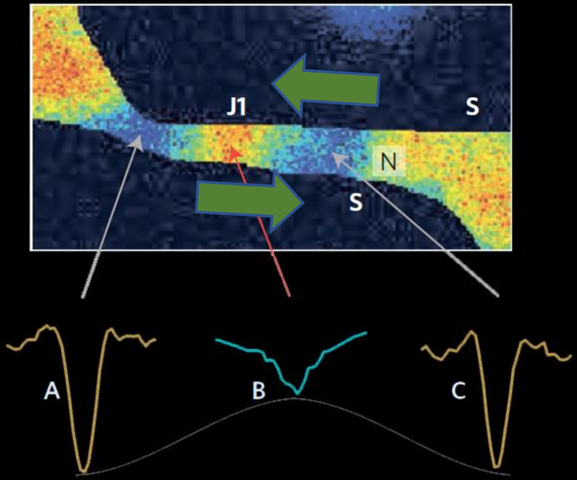




180 mT







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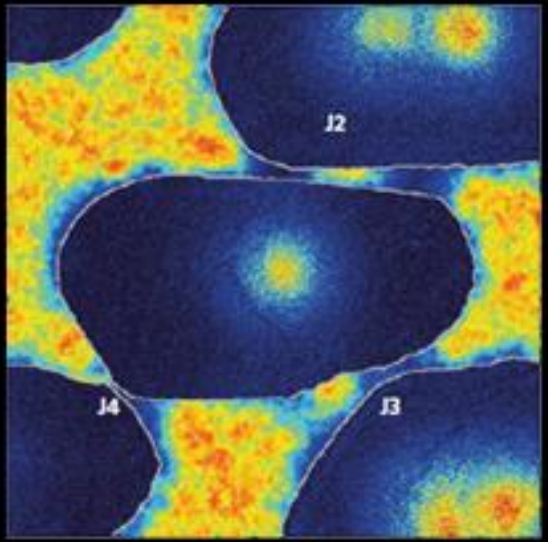
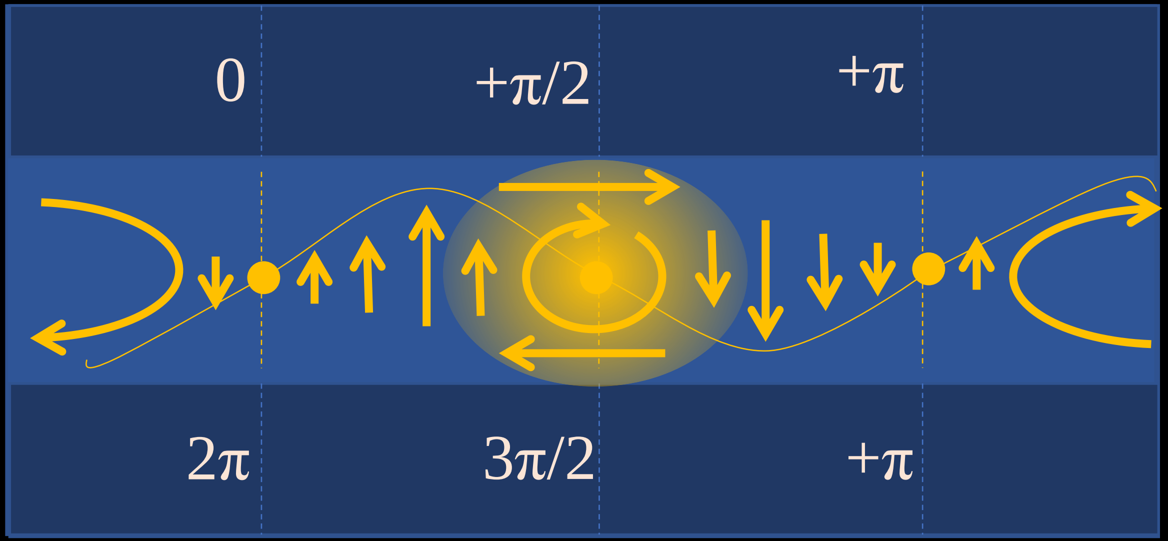
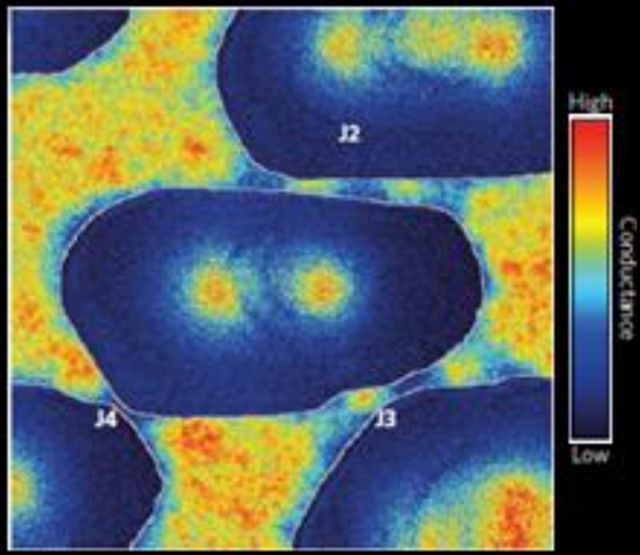
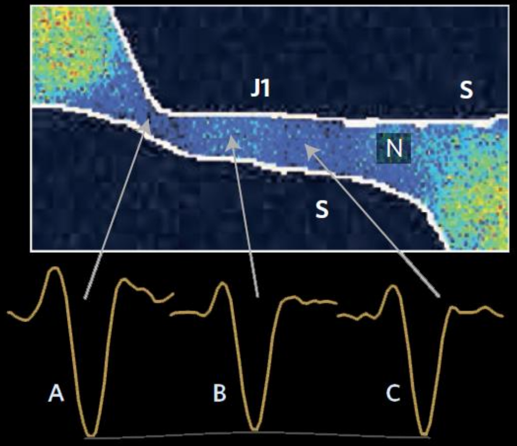
120 mT

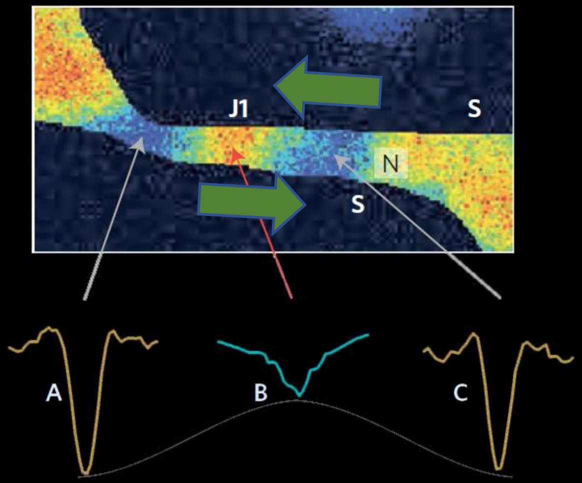




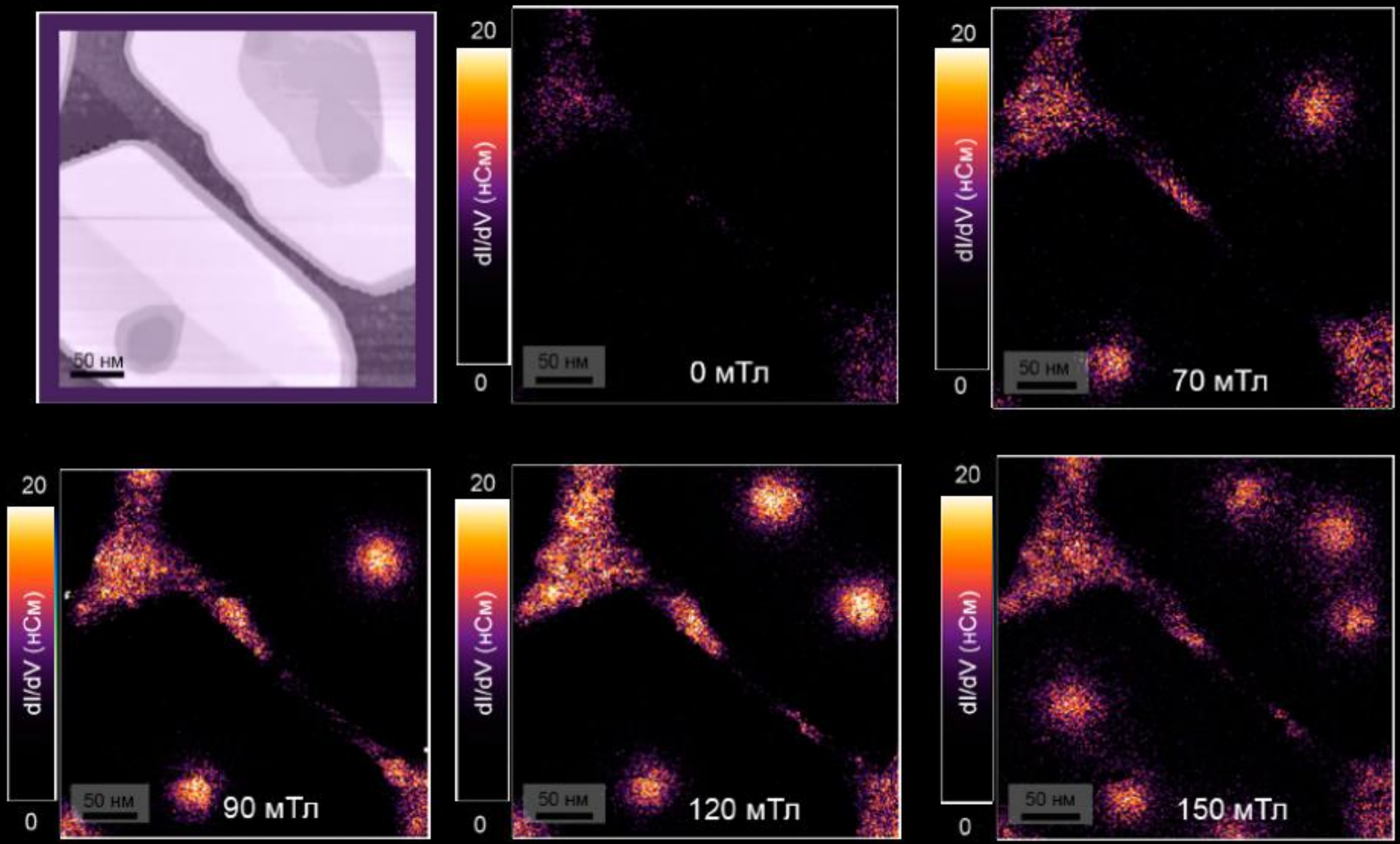
180 mT



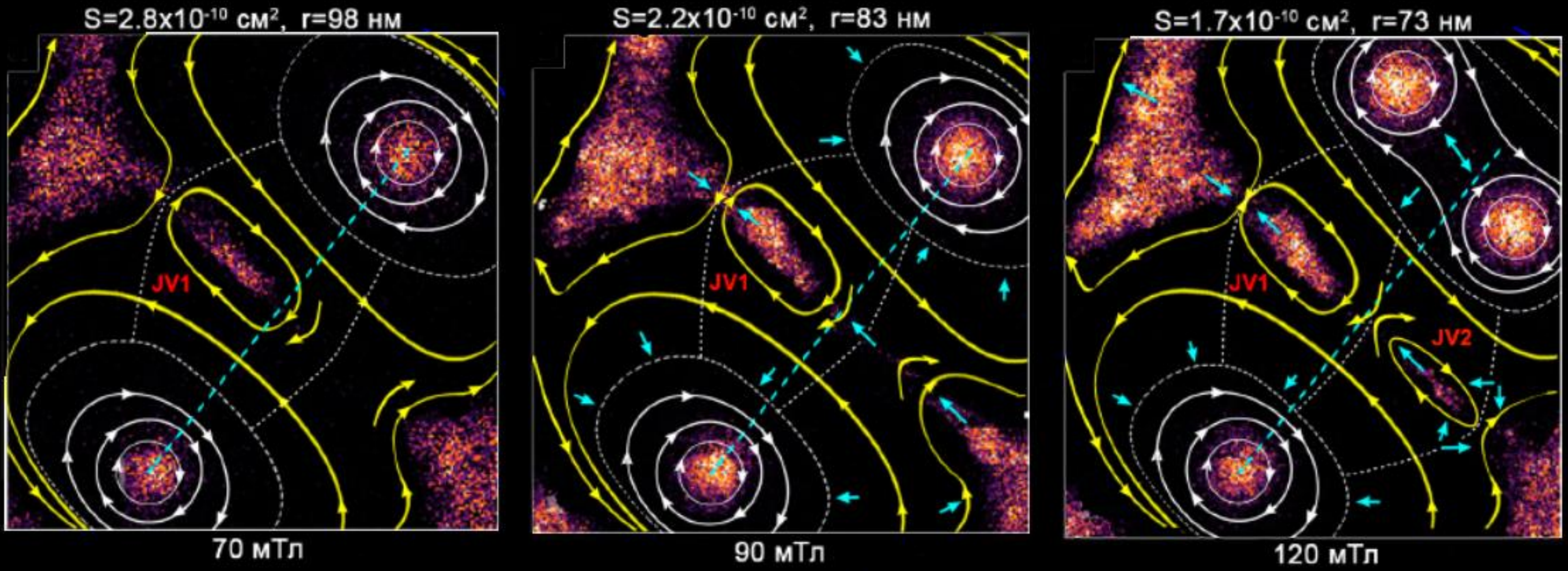




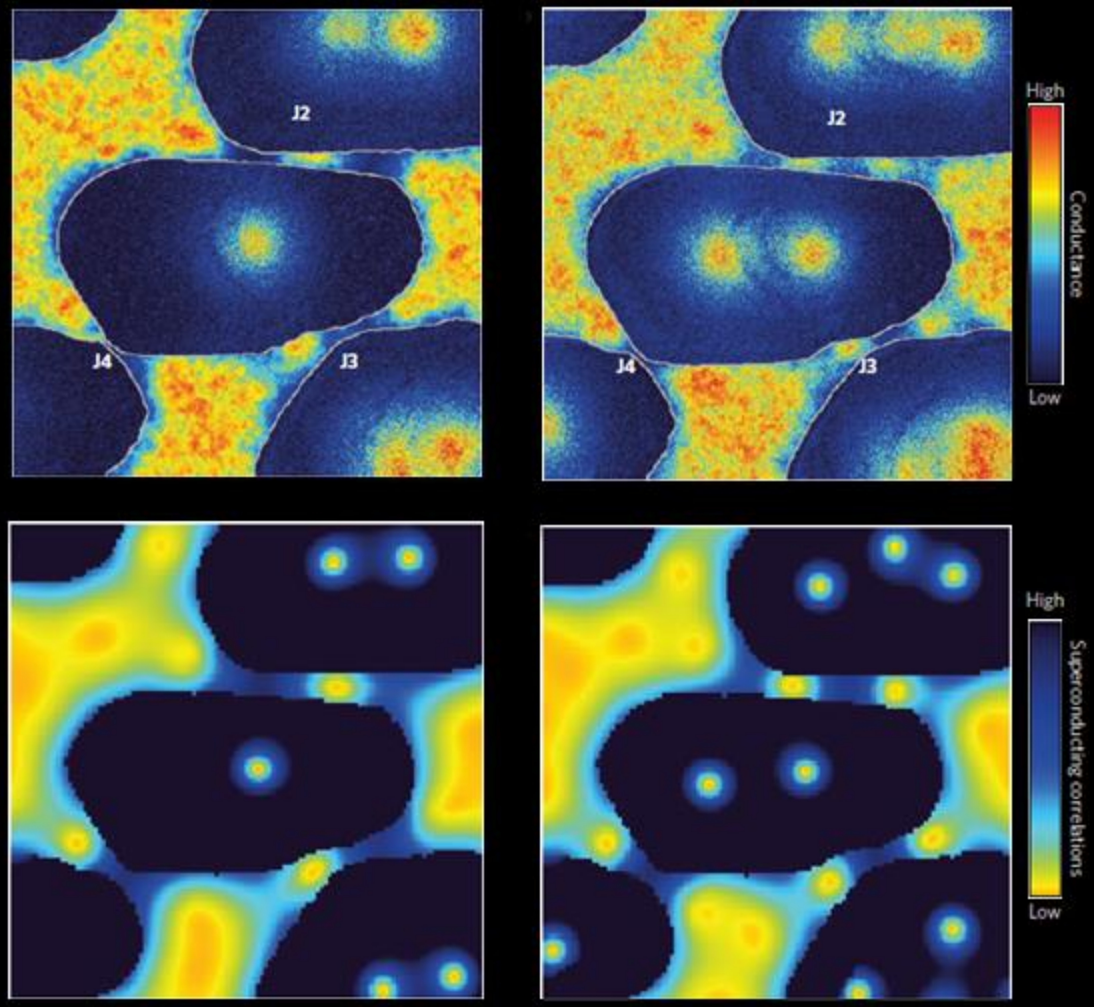
Josephson vortex: direct observation



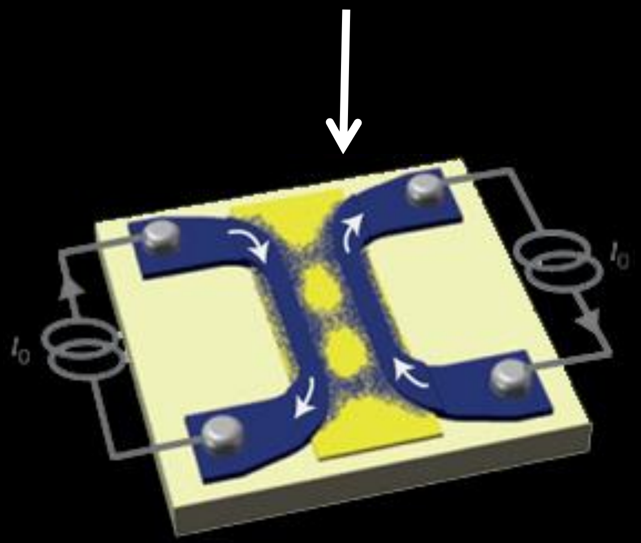
Вихрь Джозефсона: прямое наблюдение



Josephson vortex: direct observation



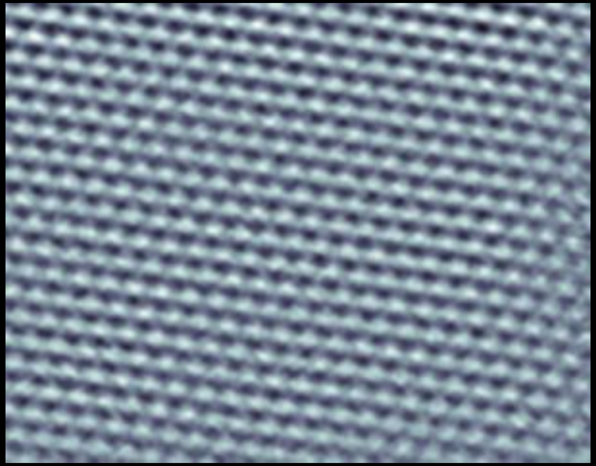
Suggested logical device



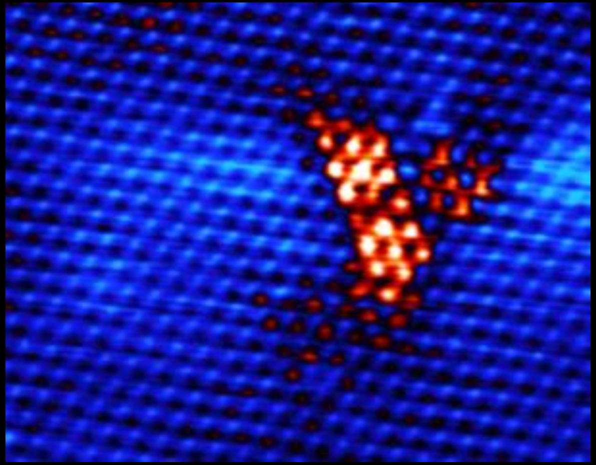
How to measure the presence of a vortex without destroying the superconductivity?

Scanning probe microscopy from SPECS к Attocube

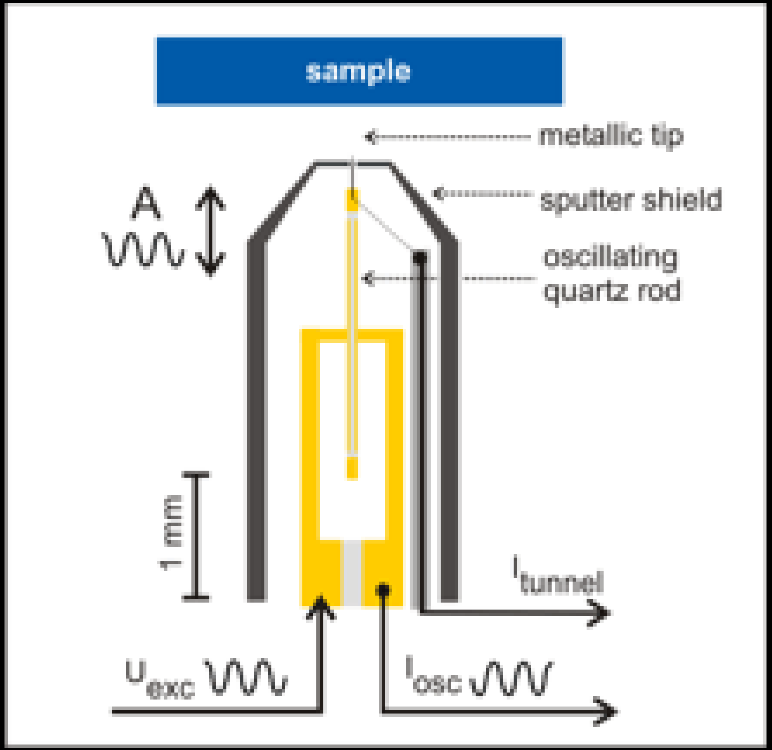
$Fe_xBi_2Te_3$

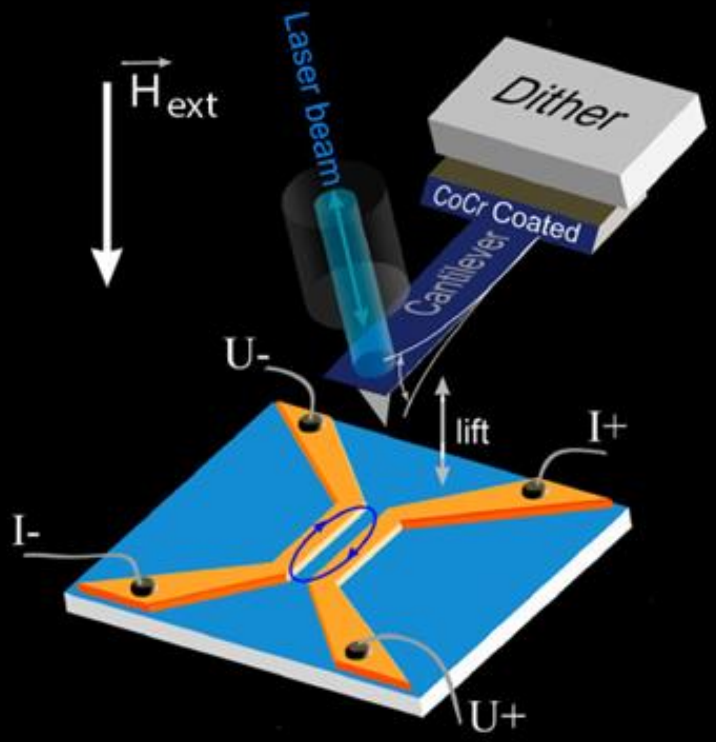


топография AFM



Торография STM





APPLIED PHYSICS LETTERS **111**, 251601 (2017)

Double Fe-impurity charge state in the topological insulator Bi_2Se_3

V. S. Stolyarov,[1,2,3,4,5,6,a)] S. V. Remizov,[7,8] D. S. Shapiro,[7,8,2] S. Pons,[1] S. Vlaic,[1] H. Aubin,[1] D. S. Baranov,[2,3,9] Ch. Brun,[9] L. V. Yashina,[4] S. I. Bozhko,[3] T. Cren,[9] W. V. Pogosov,[2,7,10] and D. Roditchev[1,2,9]
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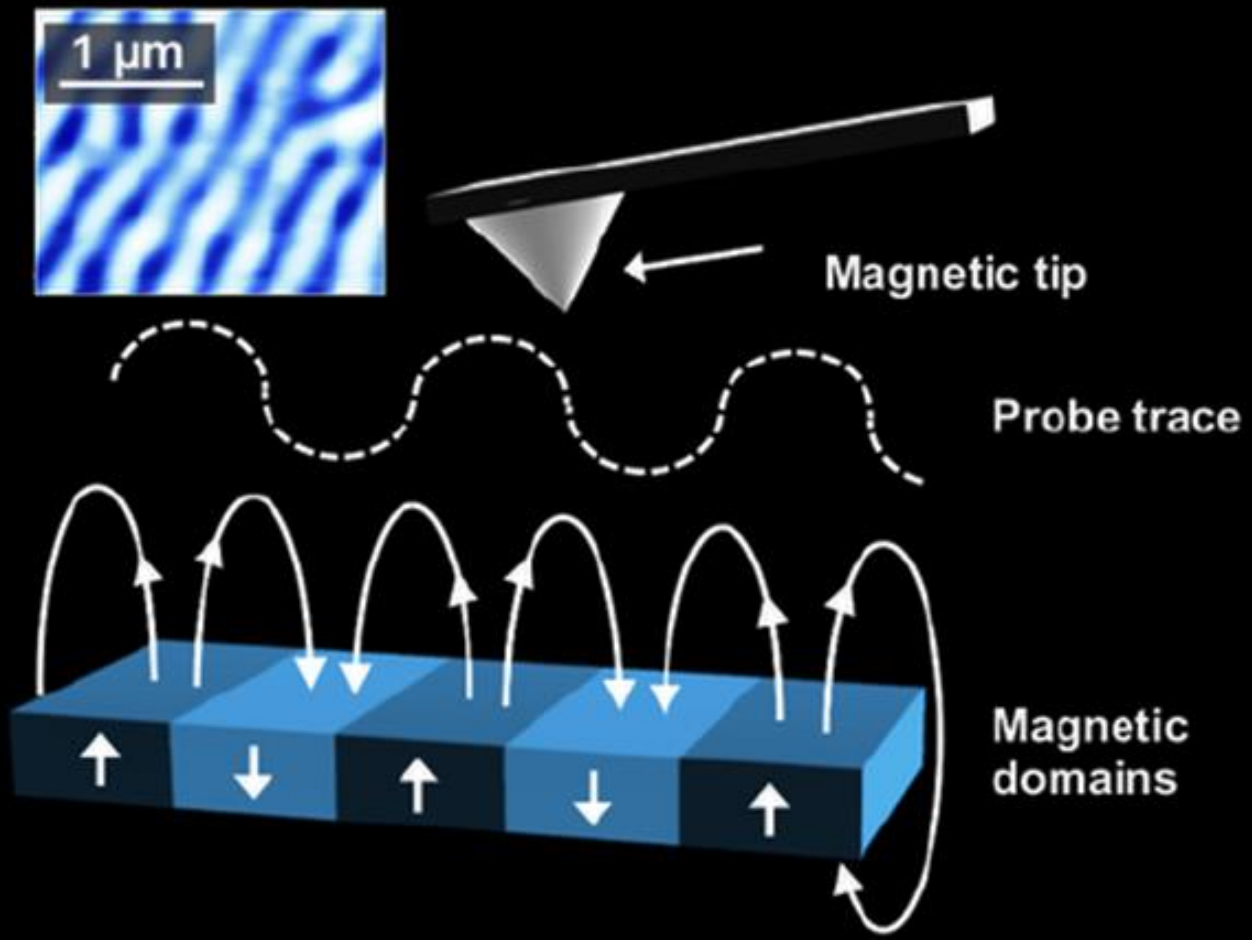
Investigation of the dynamics of Josephson vortices using a magnetic force microscope



- ✓ **STM - what is being measured: tunneling current between the metal tip and the conductive sample**
- ✓ **MFM - what is being measured: deformation of a thin cantilever due to a local magnetic force between the magnetic tip and the magnetic sample**

Investigation of the dynamics of Josephson vortices using a magnetic force microscope

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Letter

Revealing Josephson Vortex Dynamics in Proximity Junctions below Critical Current

Vasily S. Stolyarov,* Vsevolod Ruzhitskiy, Razmik A. Hovhannisyan, Sergey Grebenchuk, Andrey G. Shishkin, Olga V. Skryabina, Igor A. Golovchanskiy, Alexander A. Golubov, Nikolay V. Klenov, Igor I. Soloviev, Mikhail Yu. Kupriyanov, Alexander Andriyash, and Dimitri Roditchev

ARTICLE
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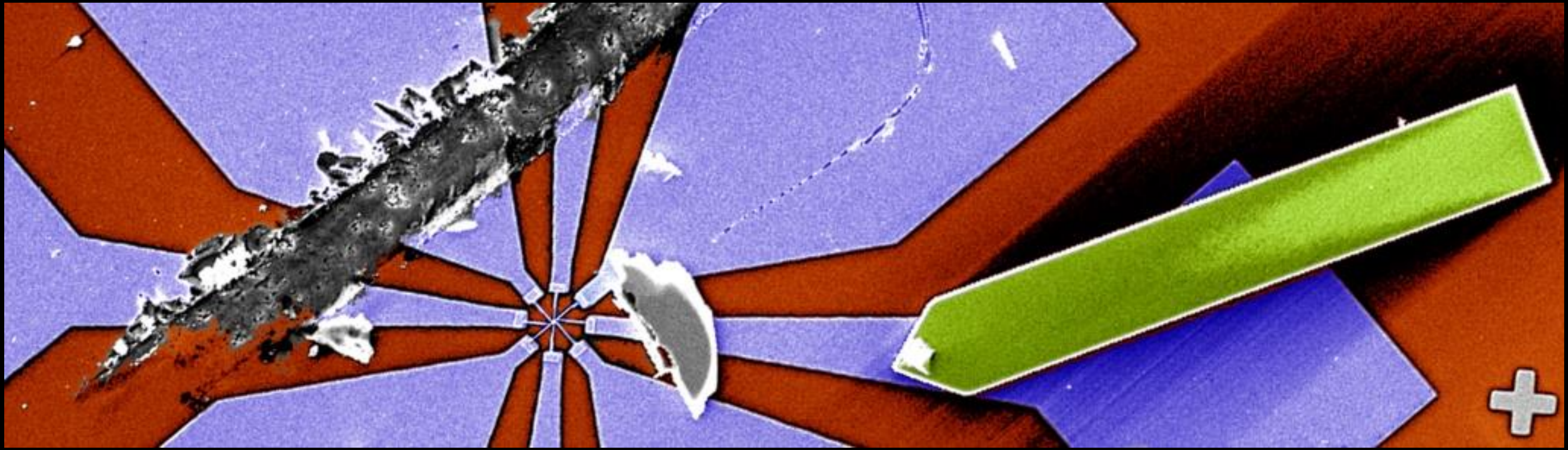
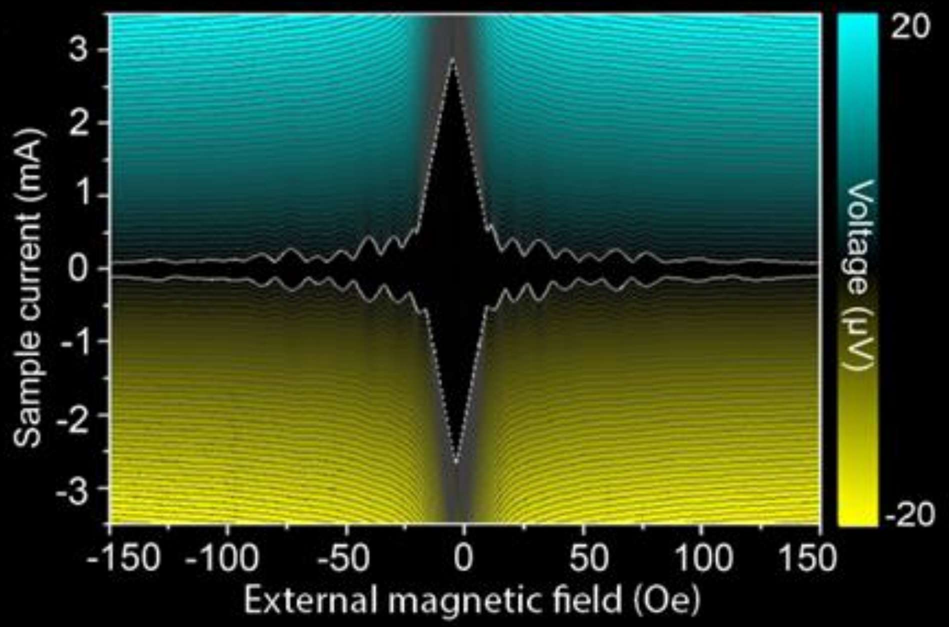
OPEN
nature COMMUNICATIONS

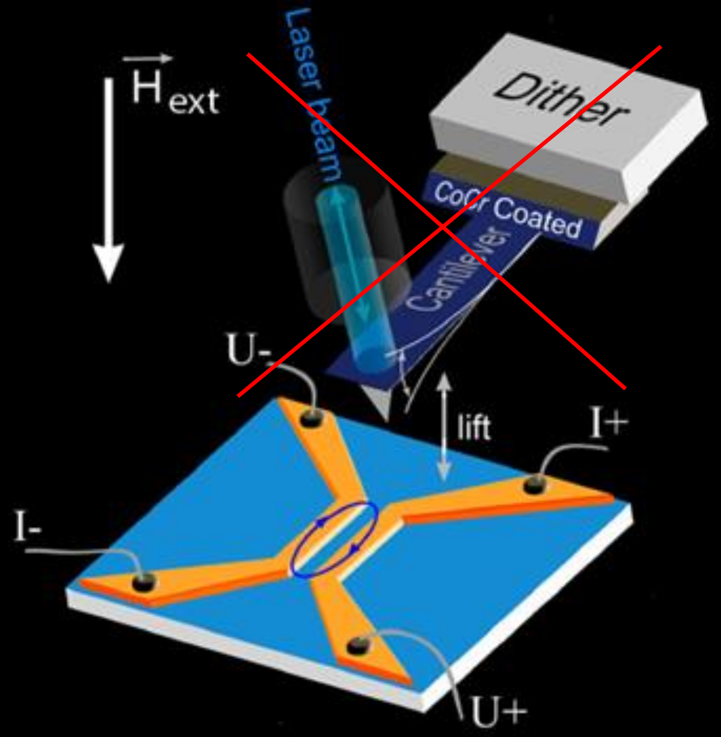
Local Josephson vortex generation and manipulation with a Magnetic Force Microscope

Viacheslav V. Dremov[1,2], Sergey Yu. Grebenchuk[1], Andrey G. Shishkin[1], Denis S. Baranov[1,3,4], Razmik A. Hovhannisyan[1], Olga V. Skryabina[1,3], Nickolay Lebedev[1], Igor A. Golovchanskiy[1,5], Vladimir I. Chichkov[5], Christophe Brun[6], Tristan Cren[6], Vladimir M. Krasnov[1,7], Alexander A. Golubov[1,8], Dimitri Roditchev[1,4,9] & Vasily S. Stolyarov[1,5,10,11]

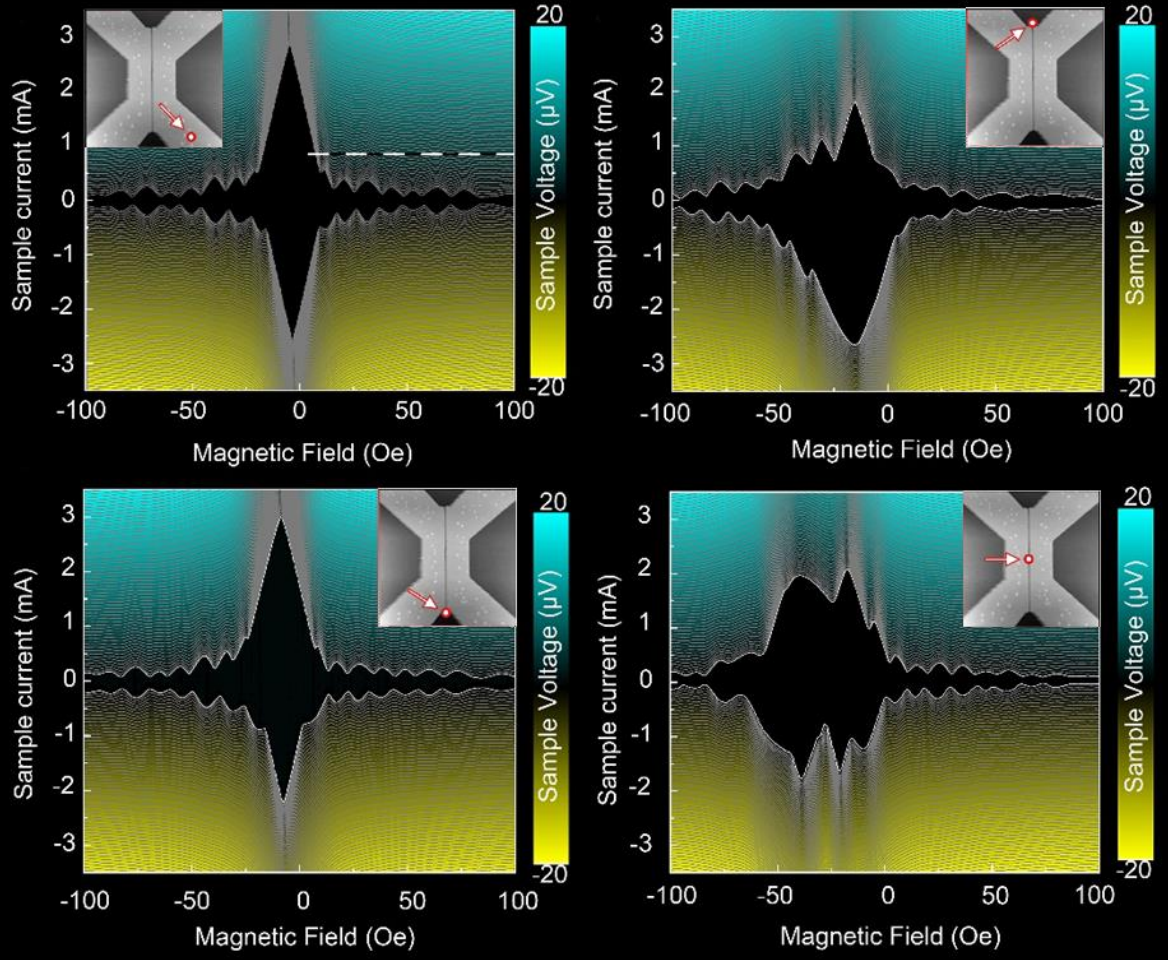


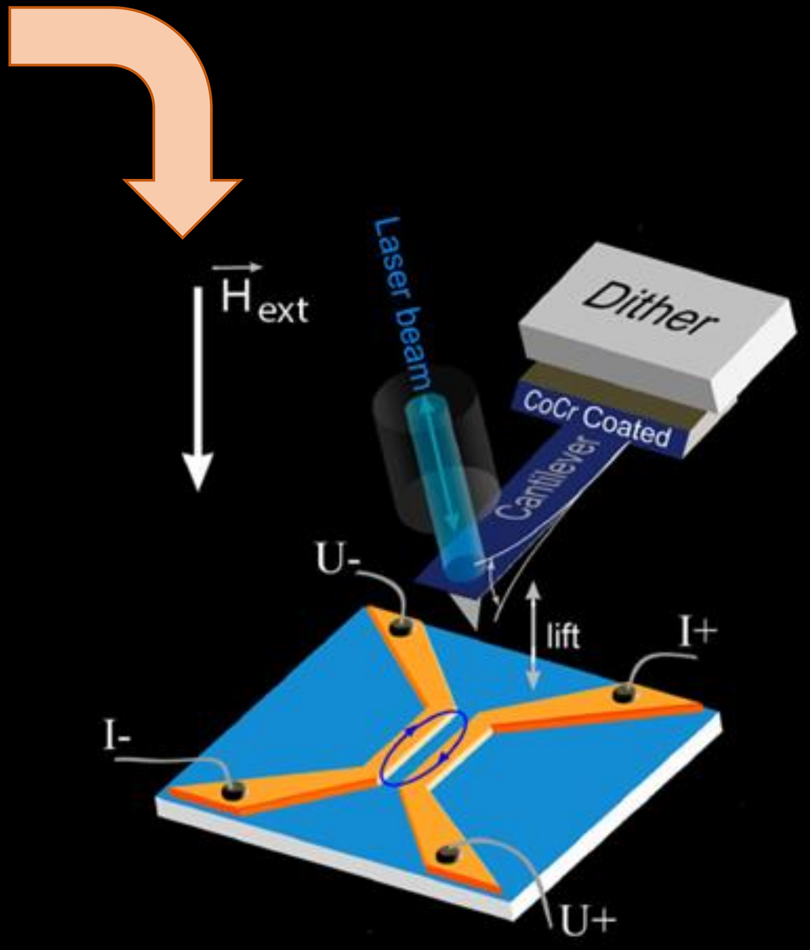
Investigation of the dynamics of Josephson vortices using a magnetic force microscope



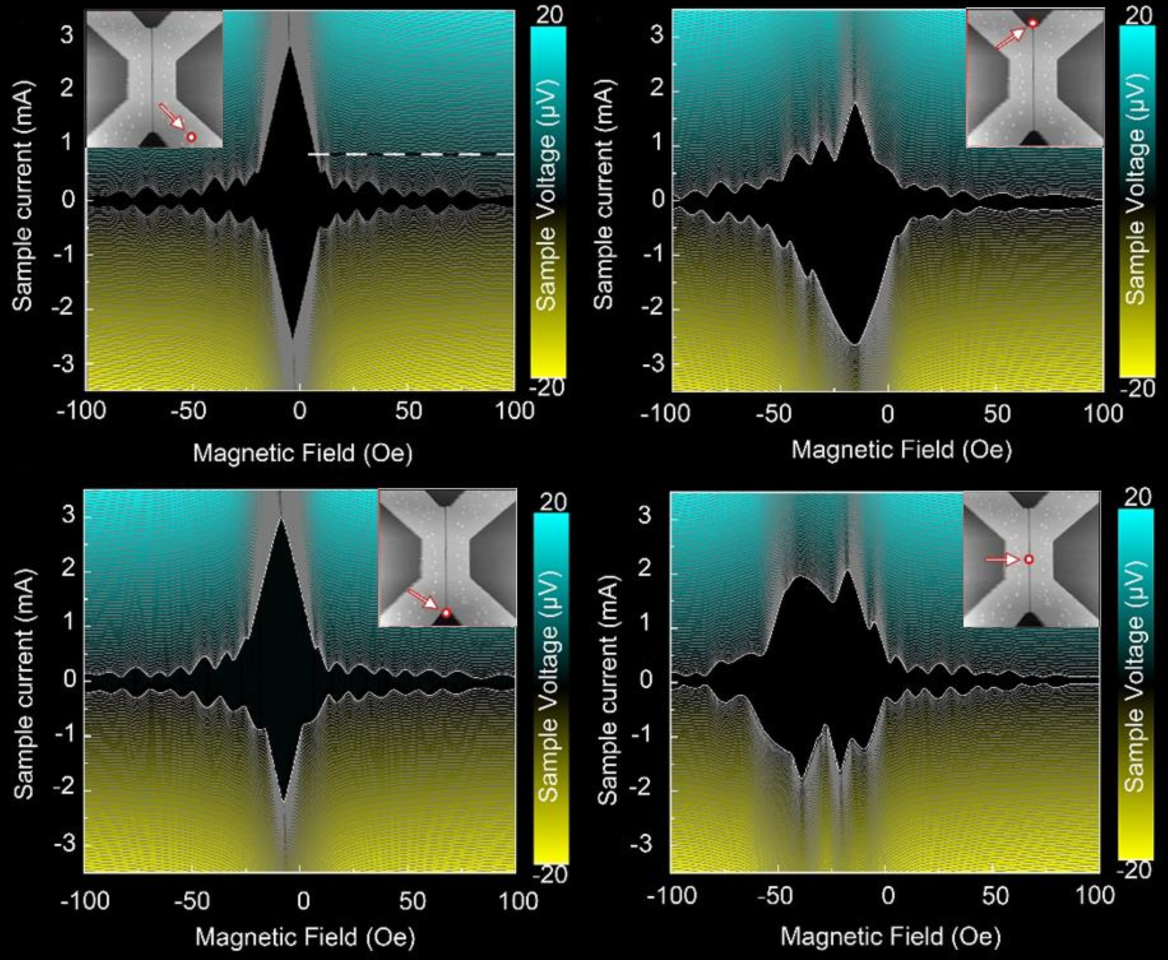


Investigation of the dynamics of Josephson vortices using a magnetic force microscope





Investigation of the dynamics of Josephson vortices using a magnetic force microscope



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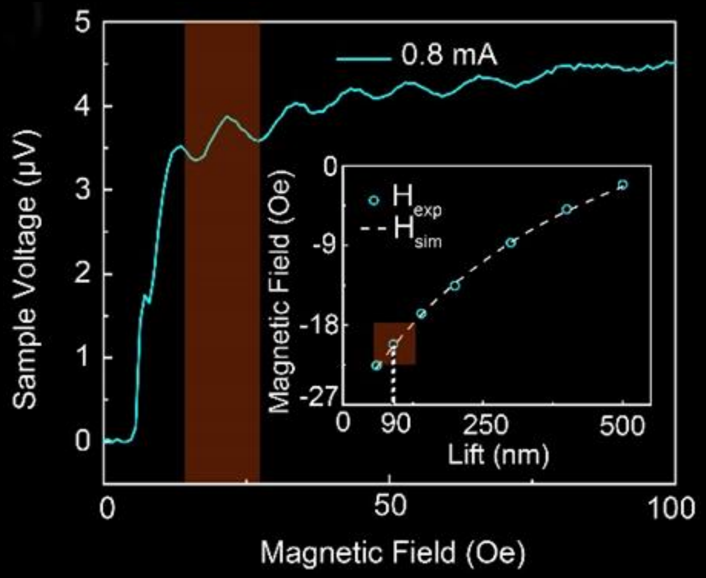
Letter

Lateral Josephson Junctions as Sensors for Magnetic Microscopy at Nanoscale

Razmik A. Hovhannisyan, Sergey Yu. Grebenchuk, Denis S. Baranov, Dimitri Roditchev, and Vasily S. Stolyarov*



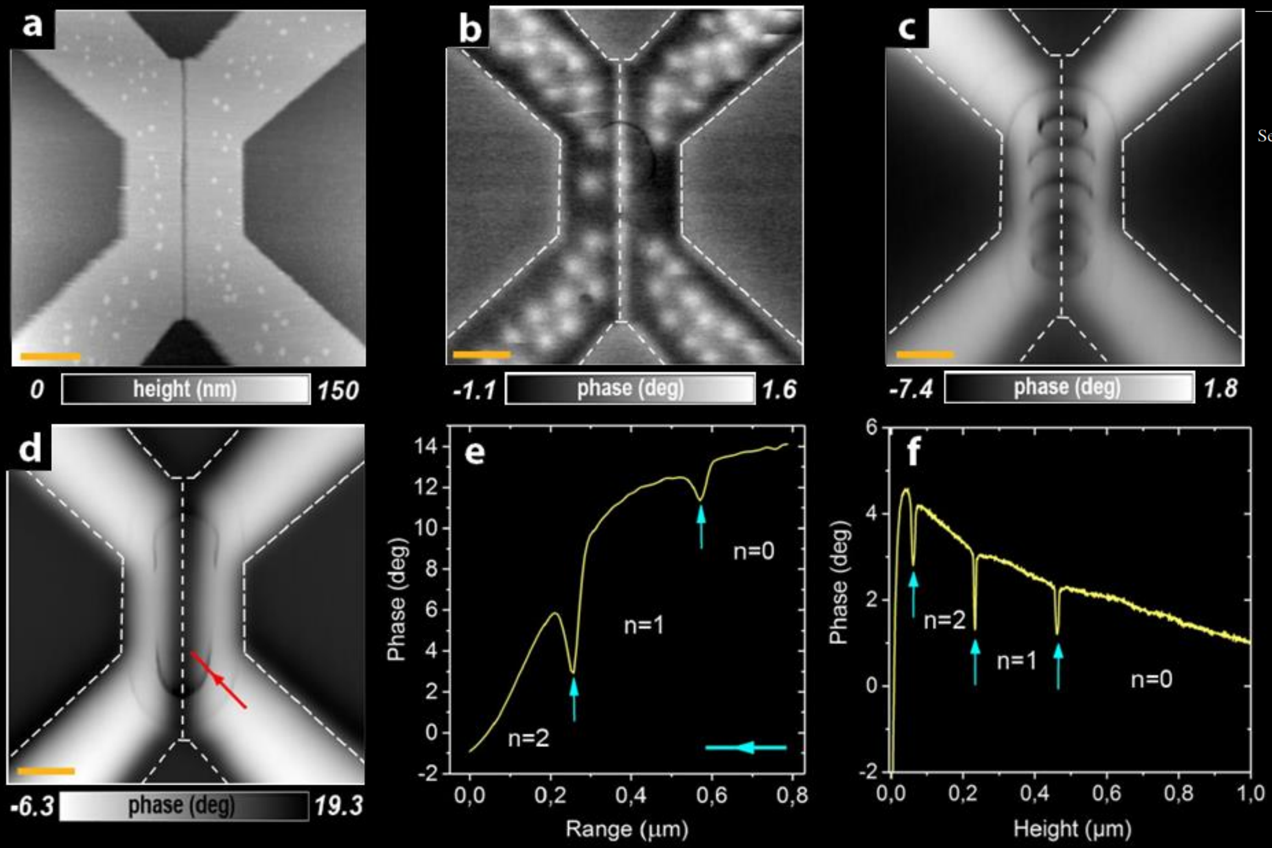
Investigation of the dynamics of Josephson vortices using a magnetic force microscope

a: topographic AFM image of the device

b: when the device is field cooled in a 90 Oe (the tip is raised by 150 nm).

c: when a field of 90 Oe is applied to the device in zero field cooled (the tip is raised by 70 nm).

d: when no magnetic field is applied to the in zero field cooled device (the tip is raised by 70 nm).



PHYSICAL REVIEW RESEARCH 2, 023105 (2020)

Observation of interacting Josephson vortex chains by magnetic force microscopy

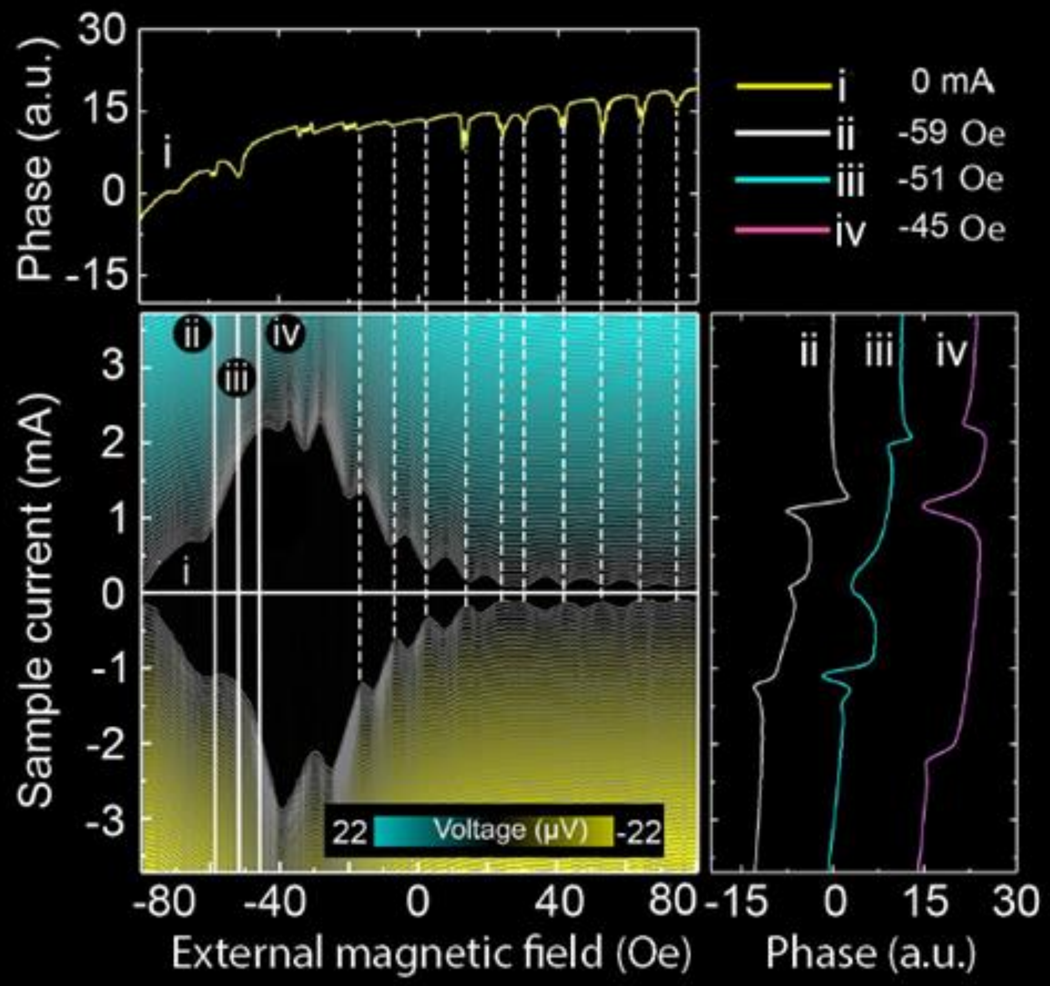
Sergey Yu. Grebenchuk,[1] Razmik A. Hovhannisyan,[1] Viacheslav V. Dremov,[1,2] Andrey G. Shishkin,[1,2] Vladimir I. Chichkov,[3] Alexander A. Golubov,[1,4] Dimitri Roditchev,[5,1] Vladimir M. Krasnov,[6,1,*] and Vasily S. Stolyarov[1,2,3,†]

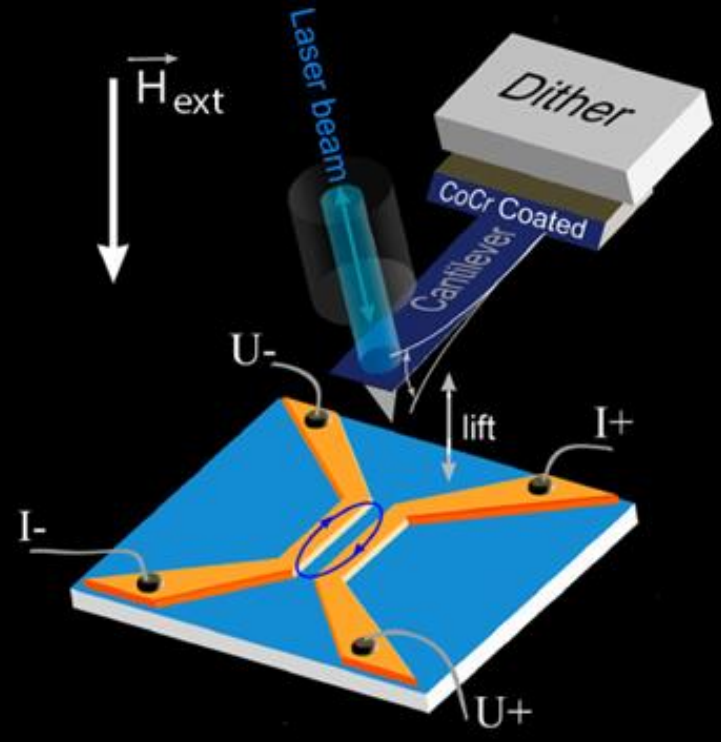
e: spatial change in the phase signal along the line indicated by the red arrow on the map.

d: each phase drop limits different Josephson configurations with vortex numbers n=0, 1, 2.

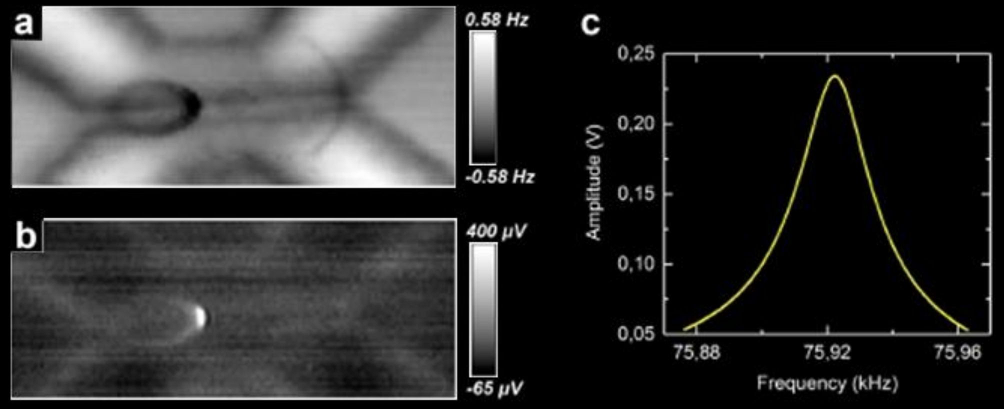
f: phase change with tip height when the tip is above the center of the device. Red arrows and numbers of vortices n=0, 1, 2 are the same as in e

Investigation of the dynamics of Josephson vortices using a magnetic force microscope

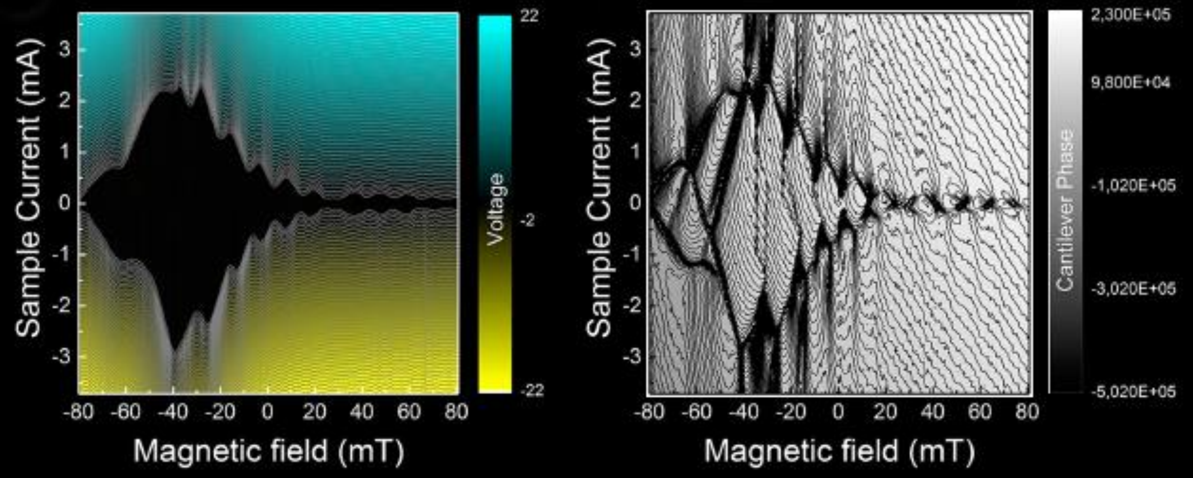




Investigation of the dynamics of Josephson vortices using a magnetic force microscope



a. MCM Frequency Shift Maps
b. Drive voltage shift. These images were measured using constant amplitude phase locked loop (PLL).
c. Resonance curve of cantilever oscillations.



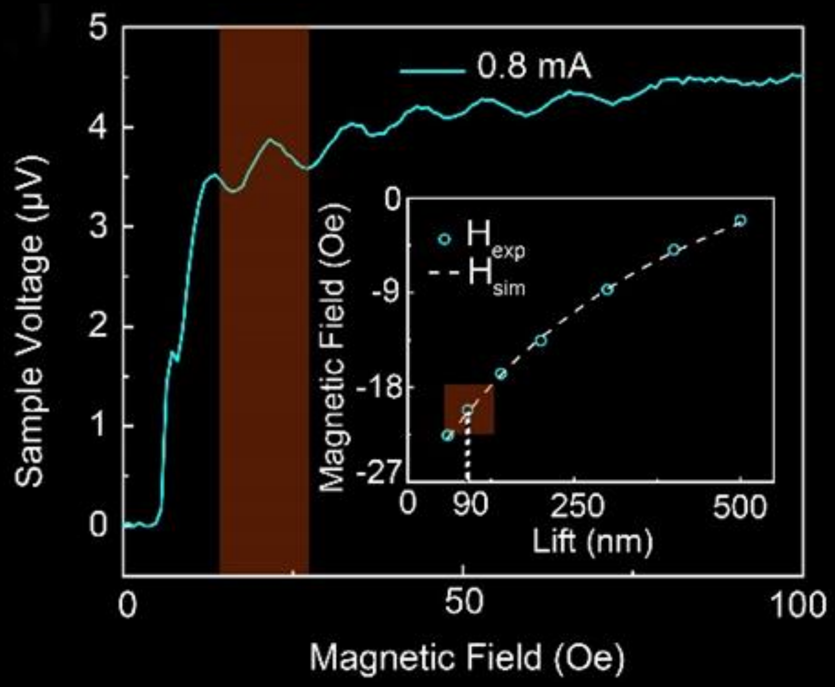
$$\delta P_{dis} \sim 2.2 \cdot 10^{-15}\ \mathrm{W}$$

$$A_{exc} = z_0/Q \rightarrow \delta A_{exc} \rightarrow \delta Q = -Q\,\delta A_{exc}/A_{exc}$$

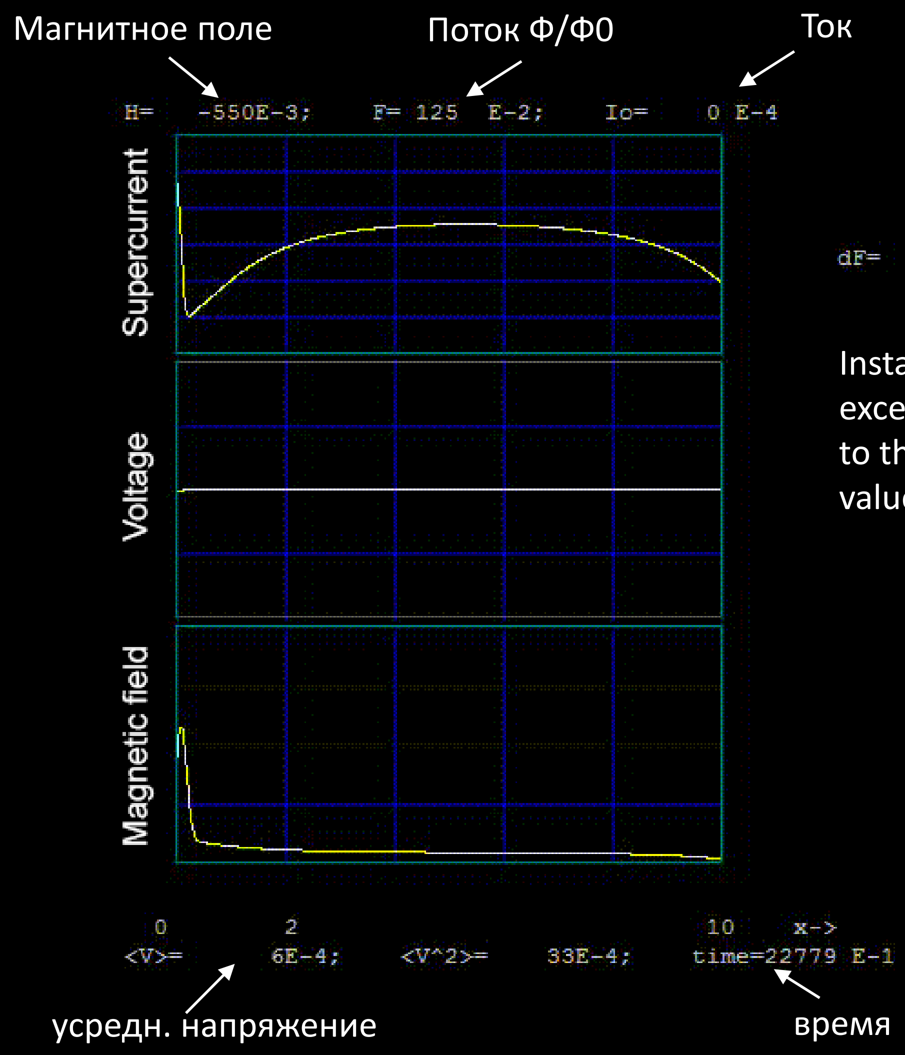
$$P_{dis} = \frac{k z_0^2 \omega_0}{2Q} \rightarrow \delta P_{dis} \rightarrow \delta P_{dis} = -\delta Q \frac{k z_0^2 \omega_0}{2Q^2} = -P_{dis}\,\delta Q/Q = P_{dis}\,\delta A_{exc}/A_{exc}$$

$$P_{dis} \sim 8.8 \cdot 10^{-14}\ \mathrm{W}$$

Investigation of the dynamics of Josephson vortices using a magnetic force microscope

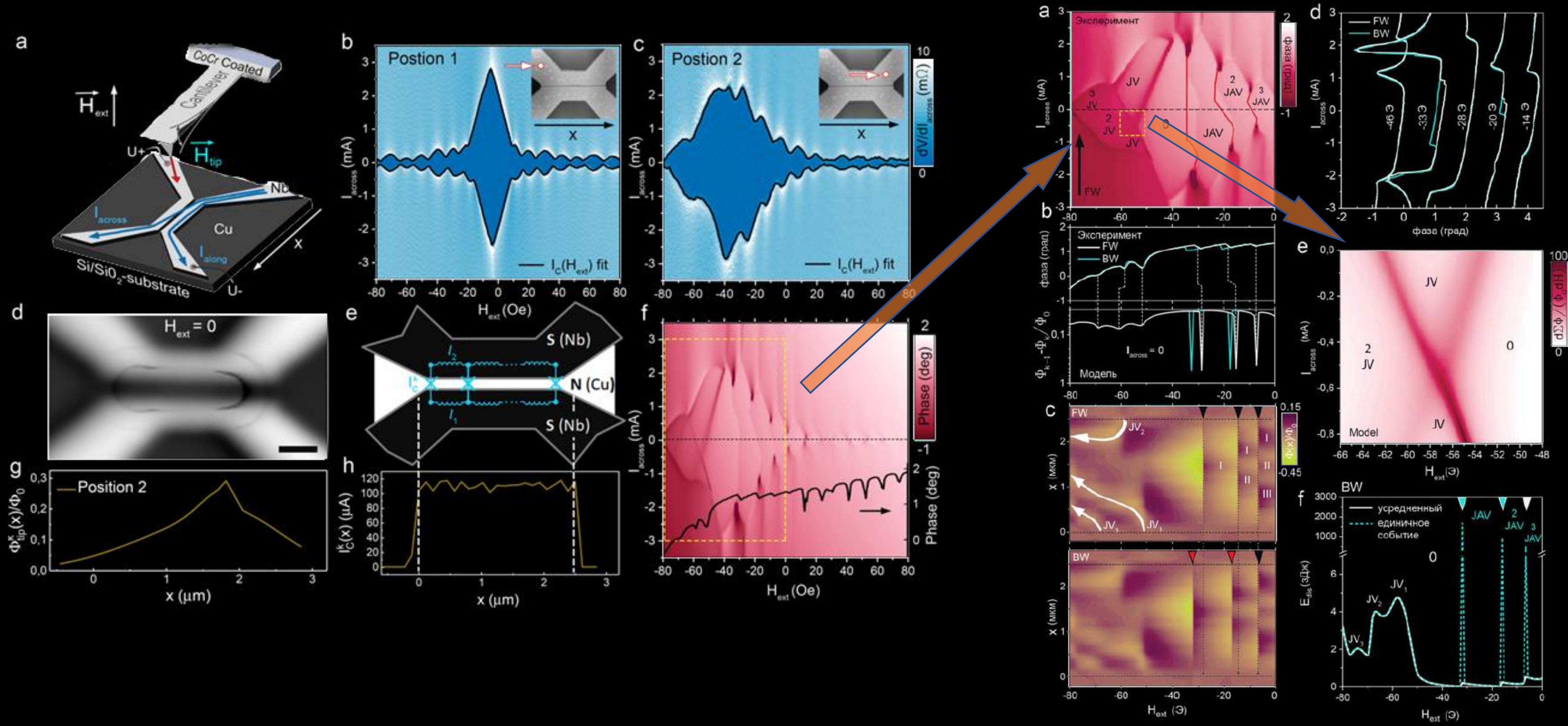


What happens in one period of oscillation of a cantilever?



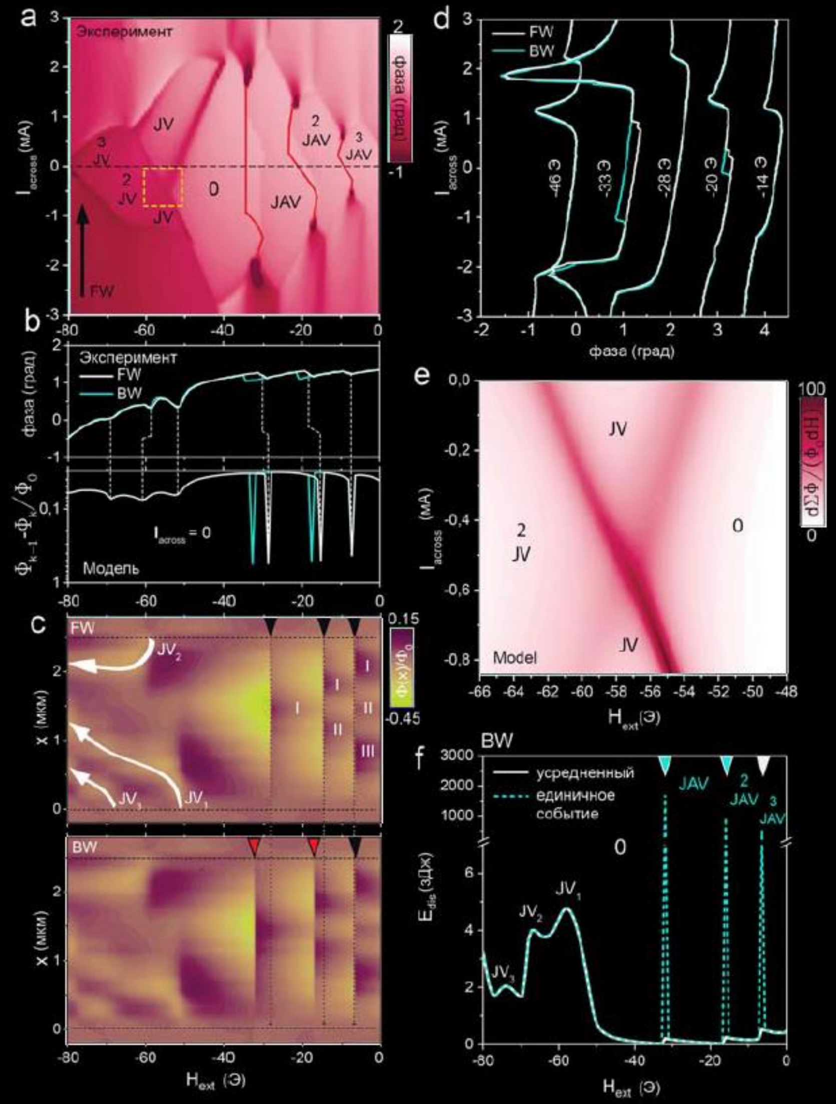
Instantaneous flux exceeded in relation to the unescaped value

Investigation of the dynamics of Josephson vortices using a magnetic force microscope



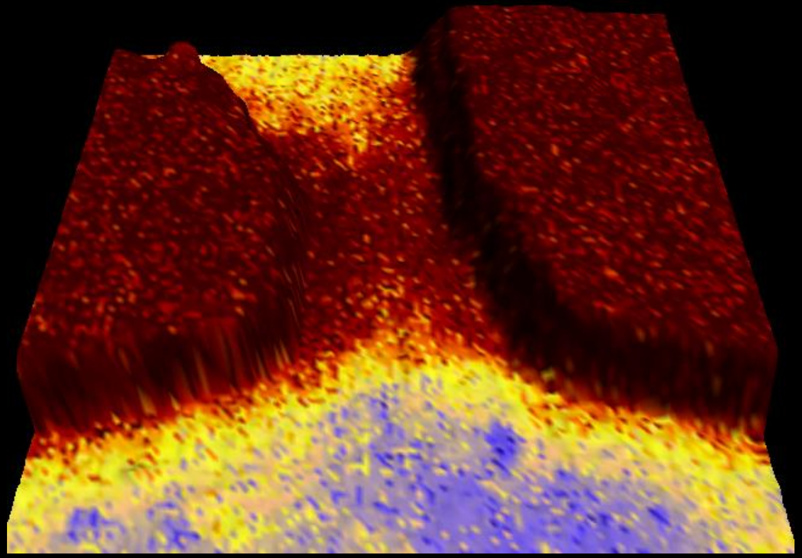
Investigation of the dynamics of Josephson vortices using a magnetic force microscope

$JV \rightarrow JV$	τ, нс	V, м/с	E_{dis}, аДж
$0JAV \rightarrow 1JAV$	0.4	$4.6 \cdot 10^3$	1.7
$1JAV \rightarrow 2JAV$	0.7	$1.7 \cdot 10^3$	0.9
$2JAV \rightarrow 3JAV$	1.0	$0.9 \cdot 10^3$	0.5

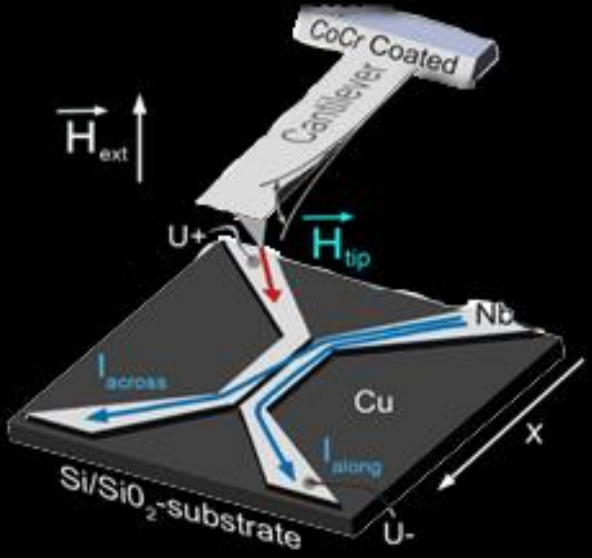


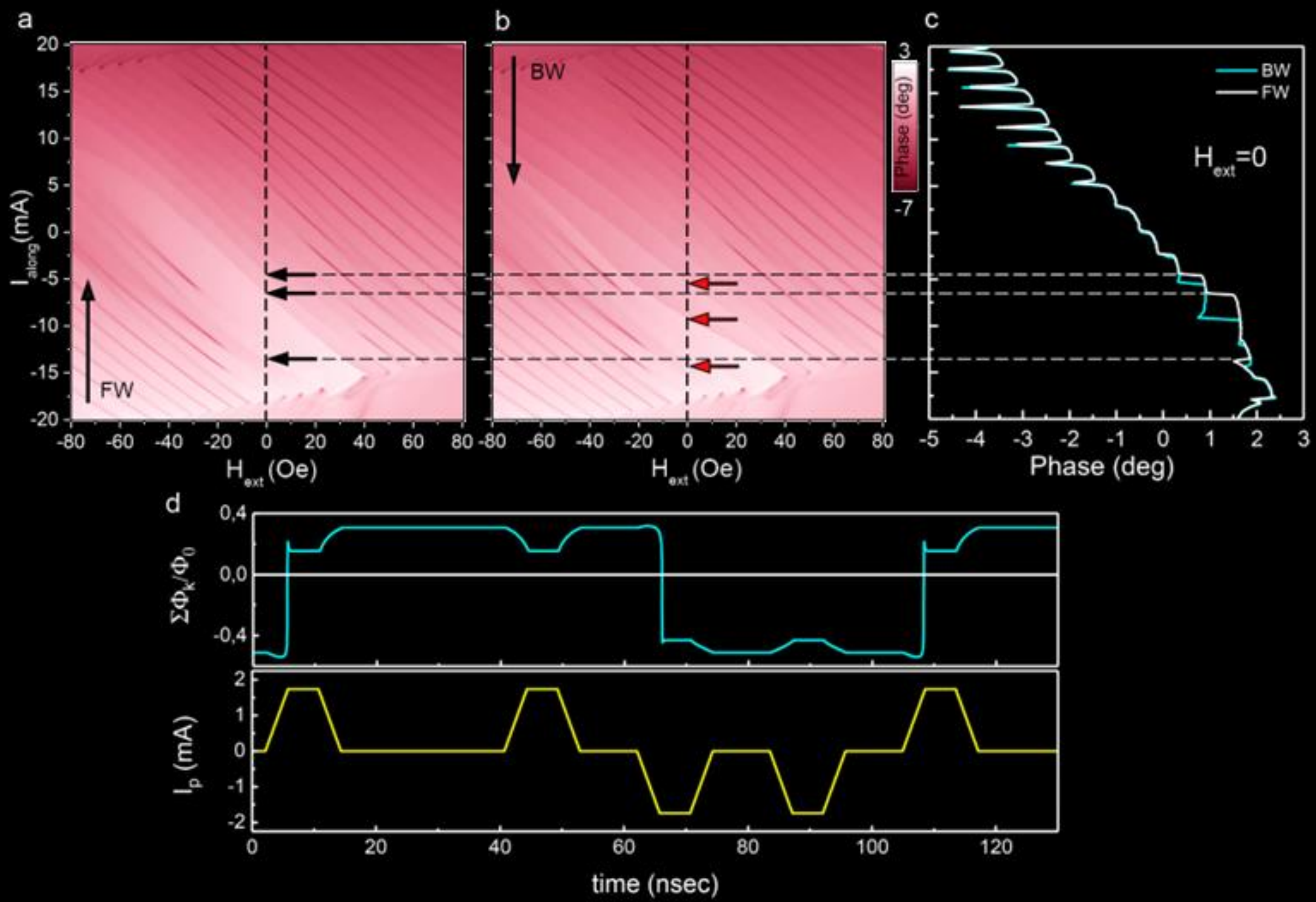
Josephson vortex as a logical state of low-dissipative devices

Part 3: **Logical state by SNS**

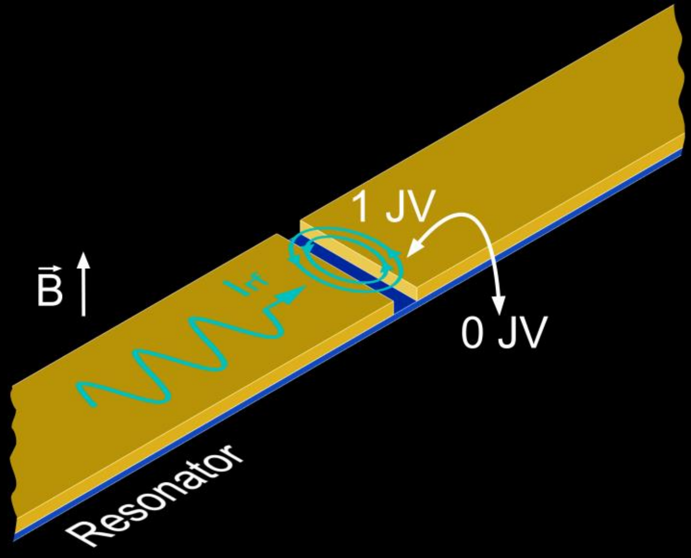


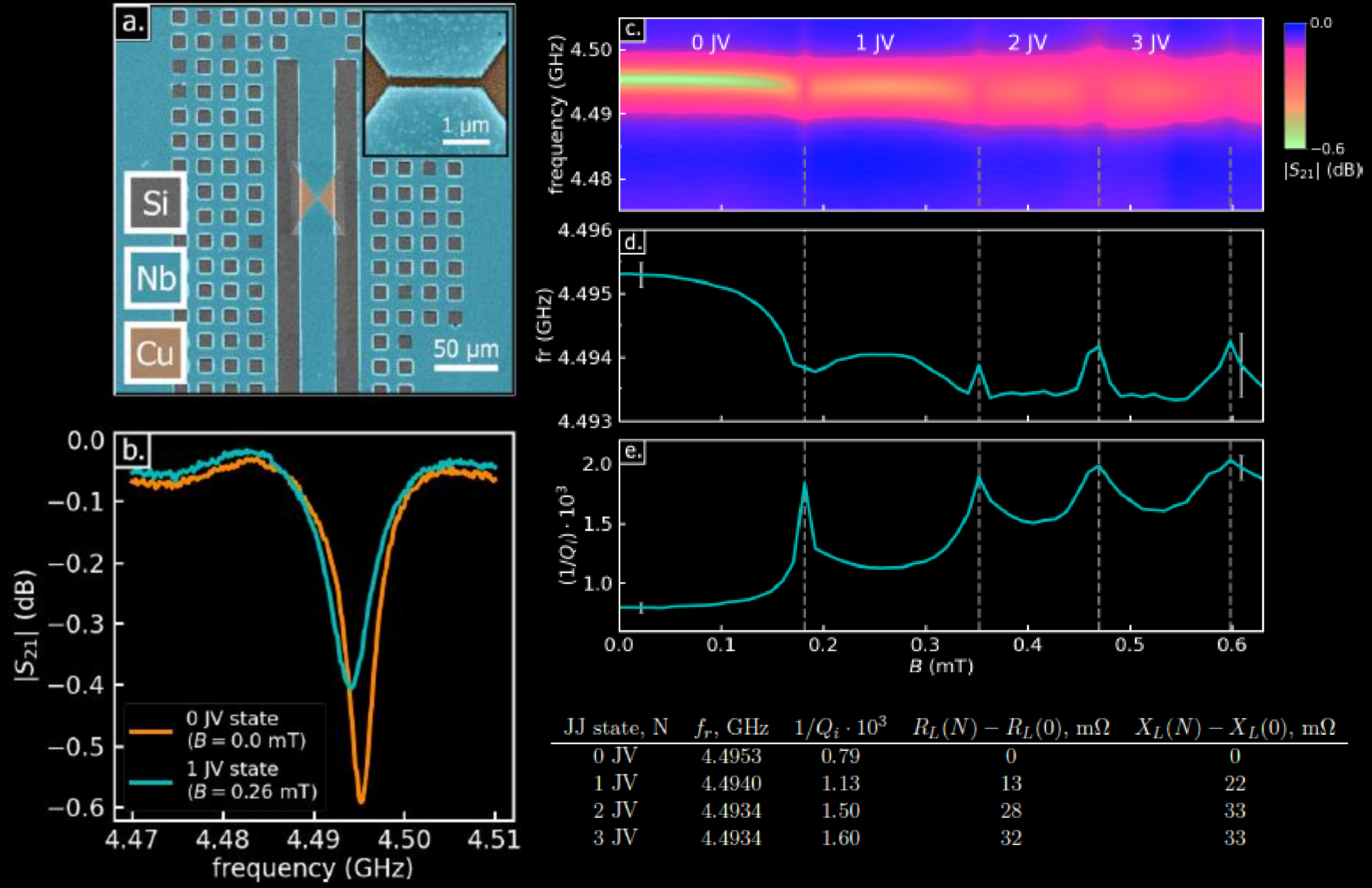
Implementation of a logical device on a chip





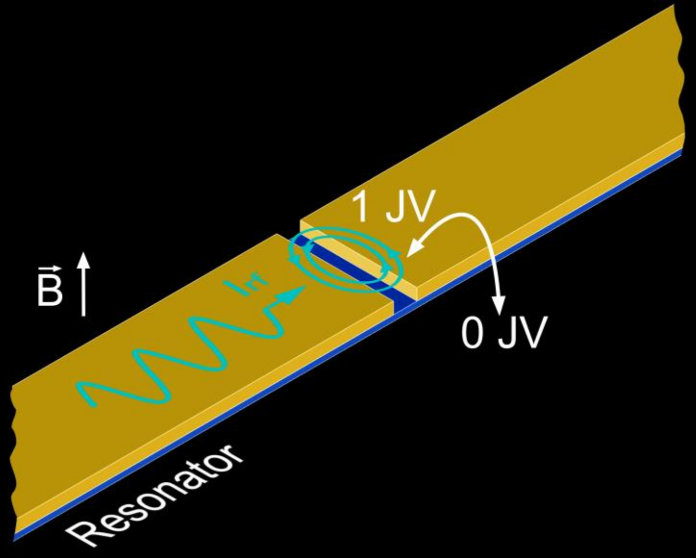
Implementation of a logical device on a chip

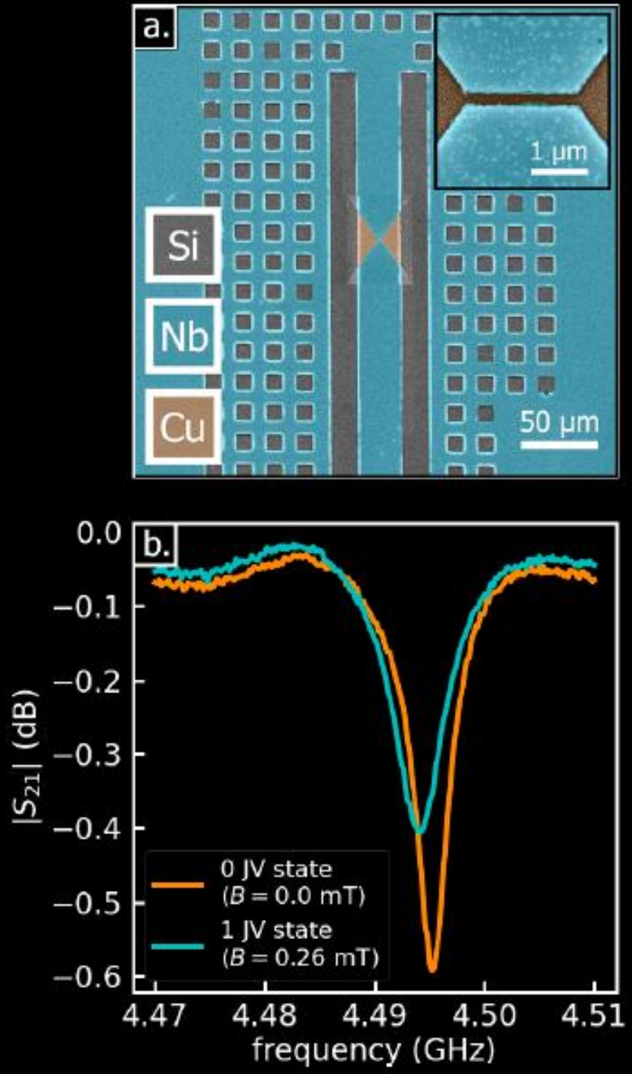


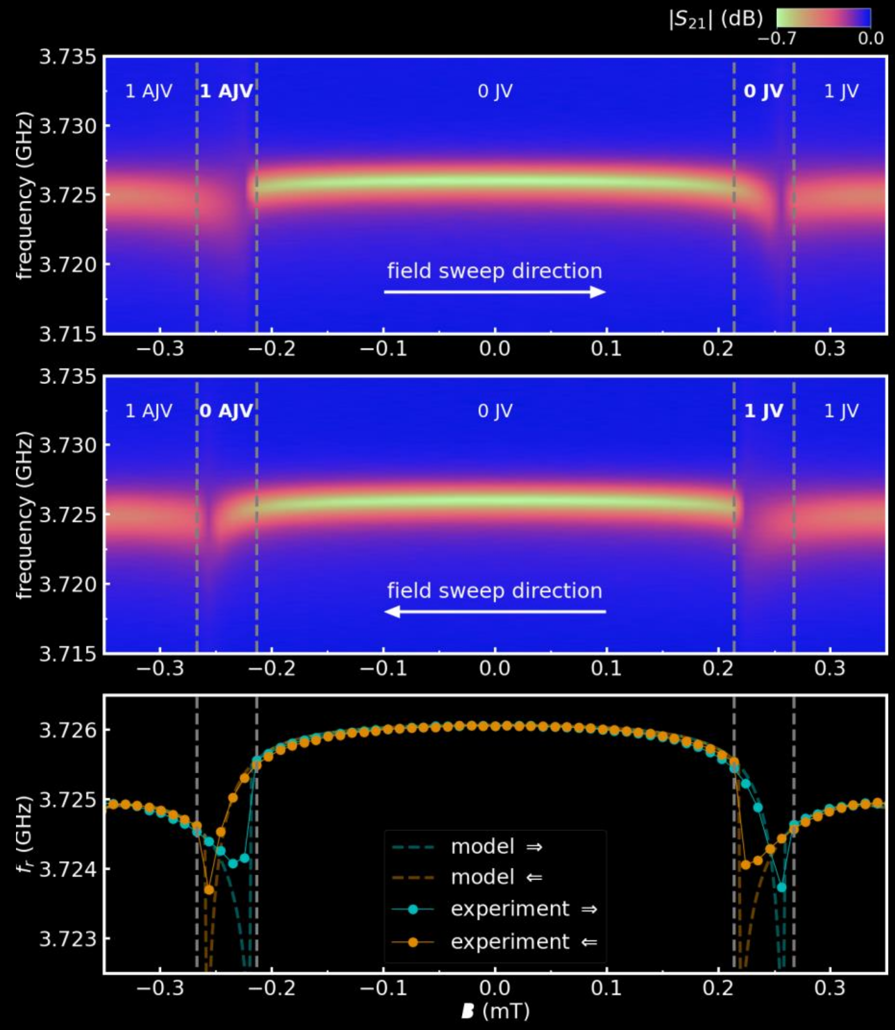


JJ state, N	f_r, GHz	$1/Q_i \cdot 10^3$	$R_L(N) - R_L(0)$, mΩ	$X_L(N) - X_L(0)$, mΩ
0 JV	4.4953	0.79	0	0
1 JV	4.4940	1.13	13	22
2 JV	4.4934	1.50	28	33
3 JV	4.4934	1.60	32	33

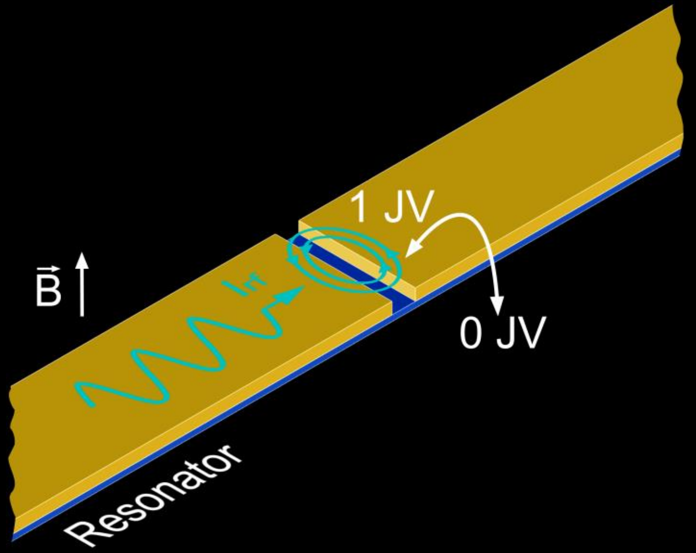
Implementation of a logical device on a chip

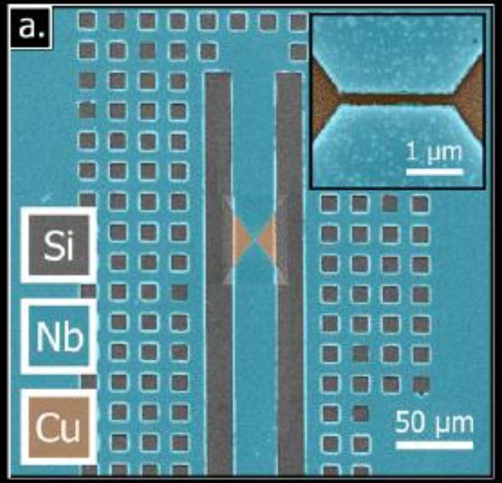


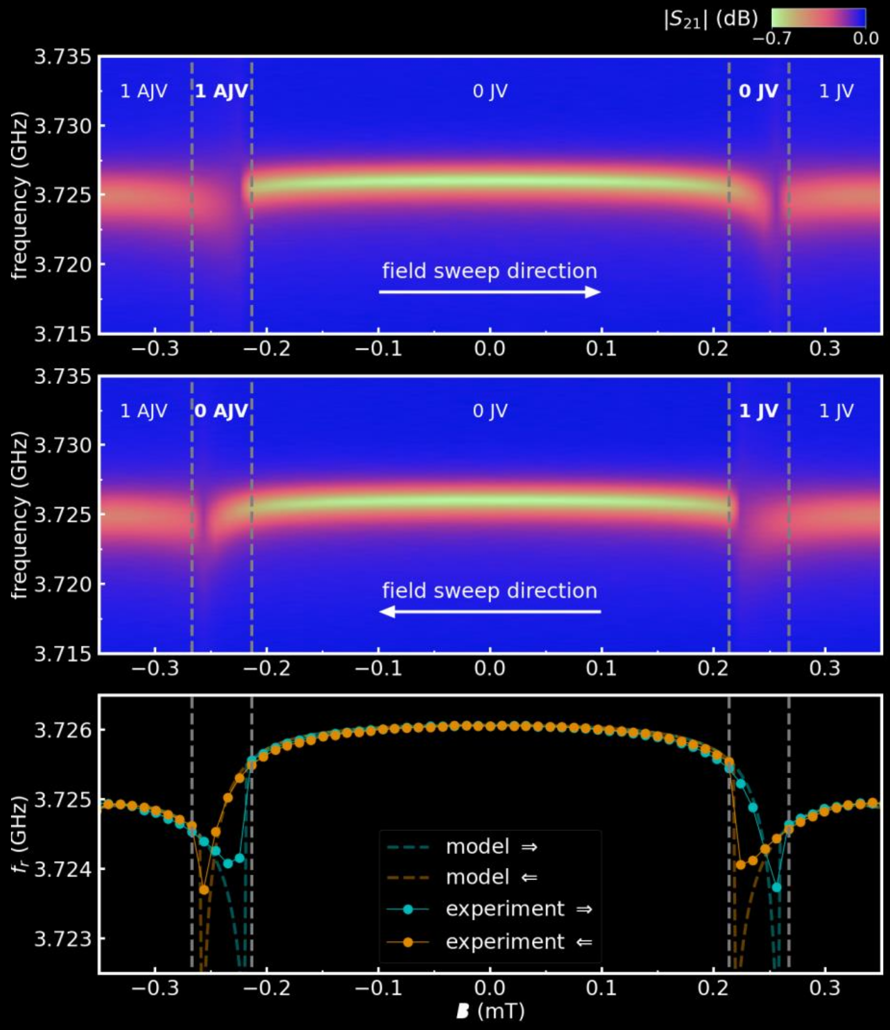


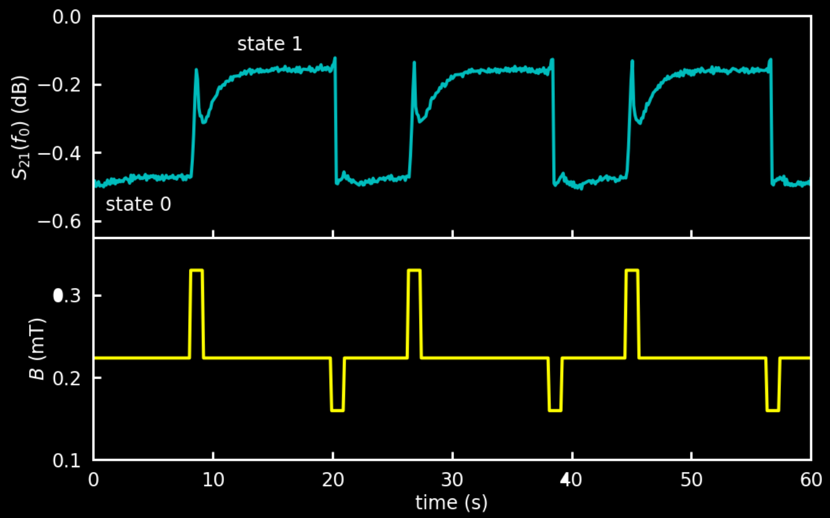


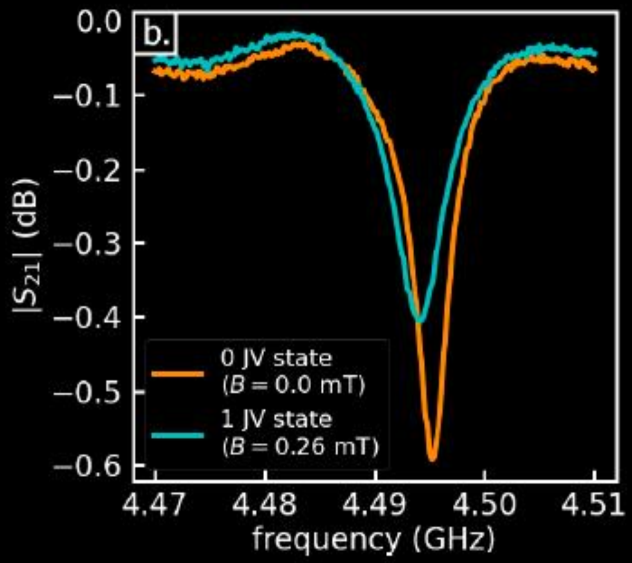
Implementation of a logical device on a chip



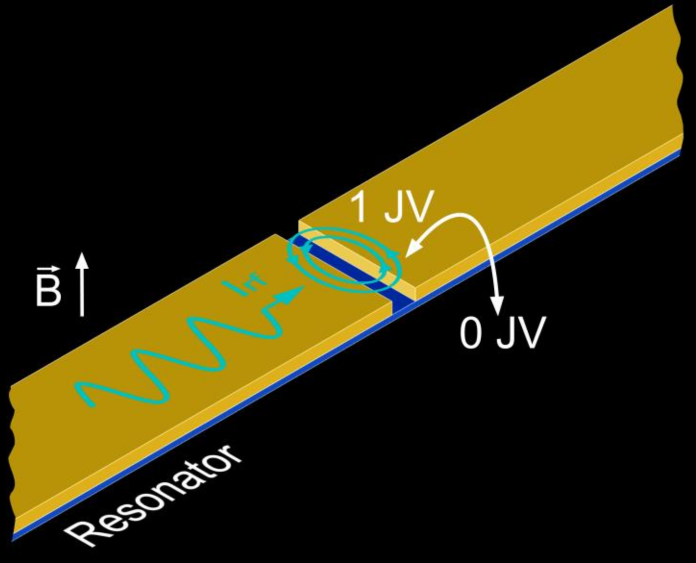


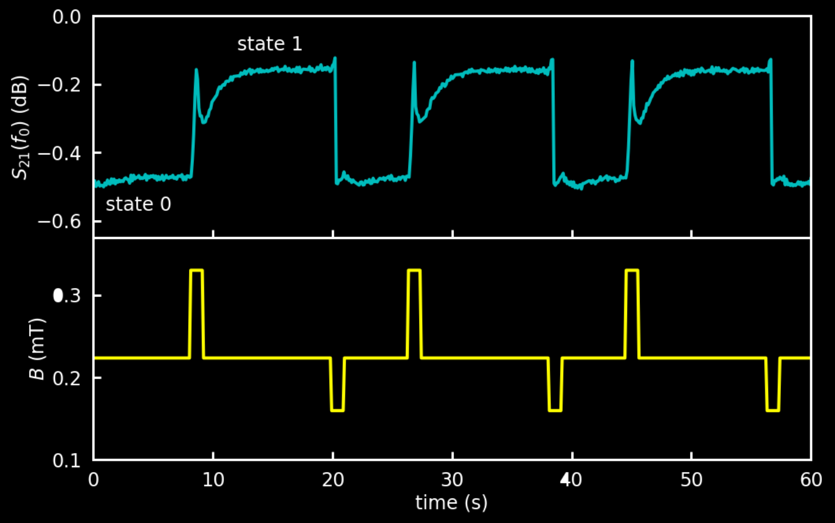


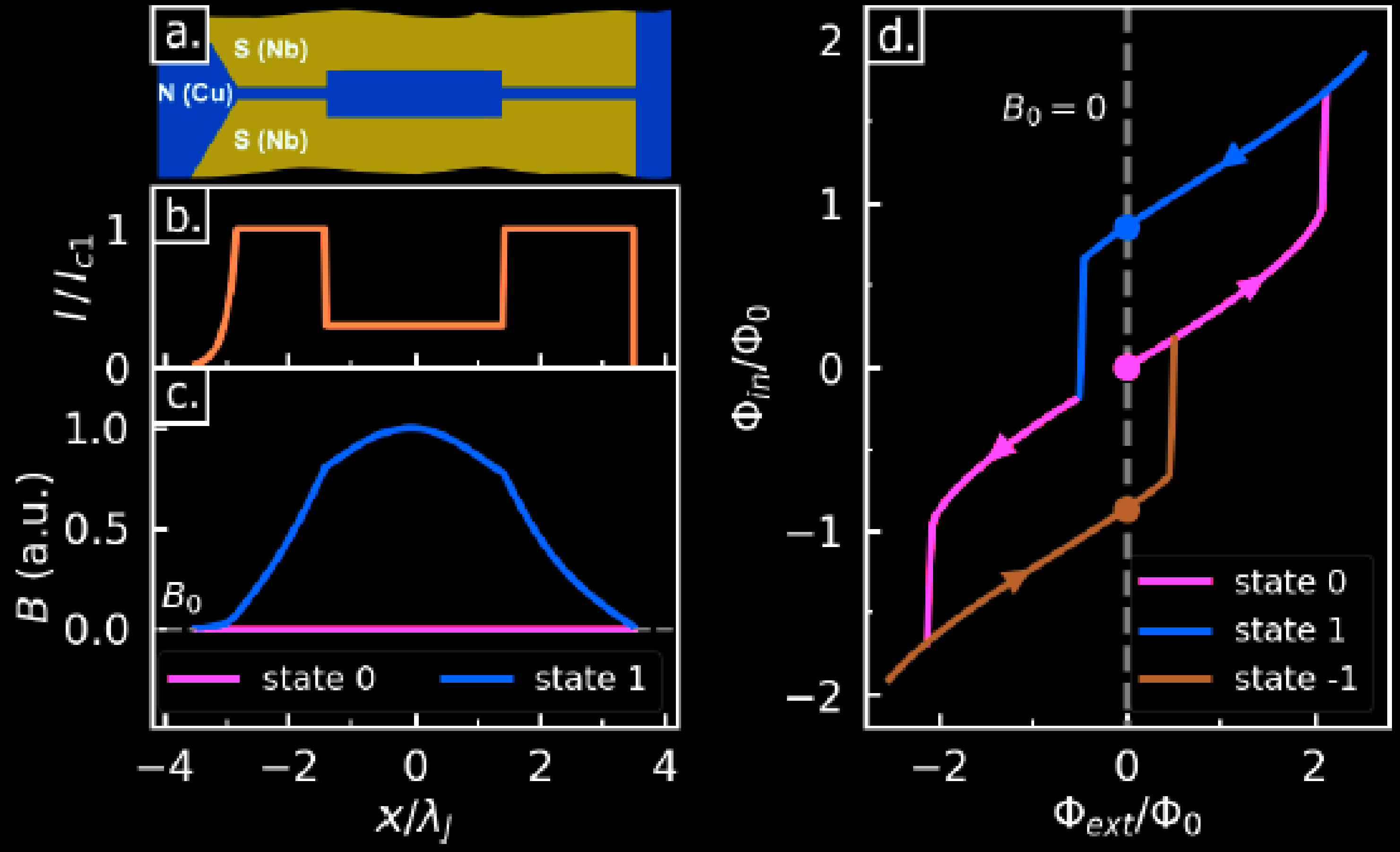




Implementation of a logical device on a chip







Submitted to the Nature Electronics

Conclusions

- To study vortex matter in hybrid systems of the S--N--S type, a self-organized network of lead islands on the Si(111) surface, interconnected by a wetting layer of amorphous lead 1~nm thick, was implemented. Experimentally, using scanning tunneling spectroscopy with high spatial and energy resolution, the presence of eddy currents that form Abrikosov (in islands) and Josephson (in regions with induced superconductivity) vortices has been demonstrated. The absence of a superconducting gap in the core of the discovered Josephson vortices, as was observed for Abrikosov vortices, is demonstrated. A self-consistent numerical simulation is carried out, which describes the experiment well.

- To demonstrate the possibility of implementing devices operating with Josephson vortices, a new method was found for generating, detecting and controlling Josephson vortices inside planar Josephson junctions using a low-temperature MFM. The experimental result is the observation of a singular response in the phase of the MFM cantilever at a certain set of parameters, which leads to pronounced rings/arcs on the MFM maps due to phase drops in the oscillations of the cantilever. The features found are identified as bifurcation points between adjacent Josephson states characterized by different numbers/positions of Josephson vortices within the junction.

- To describe the dynamic phenomena detected using the MFM, a synchronous experiment was implemented, which consists in simultaneously passing a current through the sample, applying an external magnetic field, and measuring the phase of the microscope's magnetic cantilever. To describe the experiment, a model has been developed and debugged that fully reproduces the experiment. The model describes the interaction between the cantilever and the device at bifurcation points and demonstrates that MFM can provide unique information about the state of the Josephson vortex, much richer than traditional transport measurements.

- To estimate the energy of low-dissipation processes in planar S--N--S JJ, it was experimentally demonstrated and theoretically confirmed that when generating a spatially inhomogeneous magnetic flux inside the contact, it becomes possible to create peculiar Josephson states and switching between them while globally maintaining the superconducting state of the contact.

Center for Advanced Mesoscience & Nanotechnology

Laboratory of Topological Quantum Phenomena in Superconducting Systems

Laboratory of Superconducting & Quantum Technology

ВНИИА

MIPT

Thank you for attention!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Golovchanskiy I.A.


Junior Researcher
applicant
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Leading Researcher
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Soloviev I.I.

…

Thanks to my colleagues for the fruitful collaboration!

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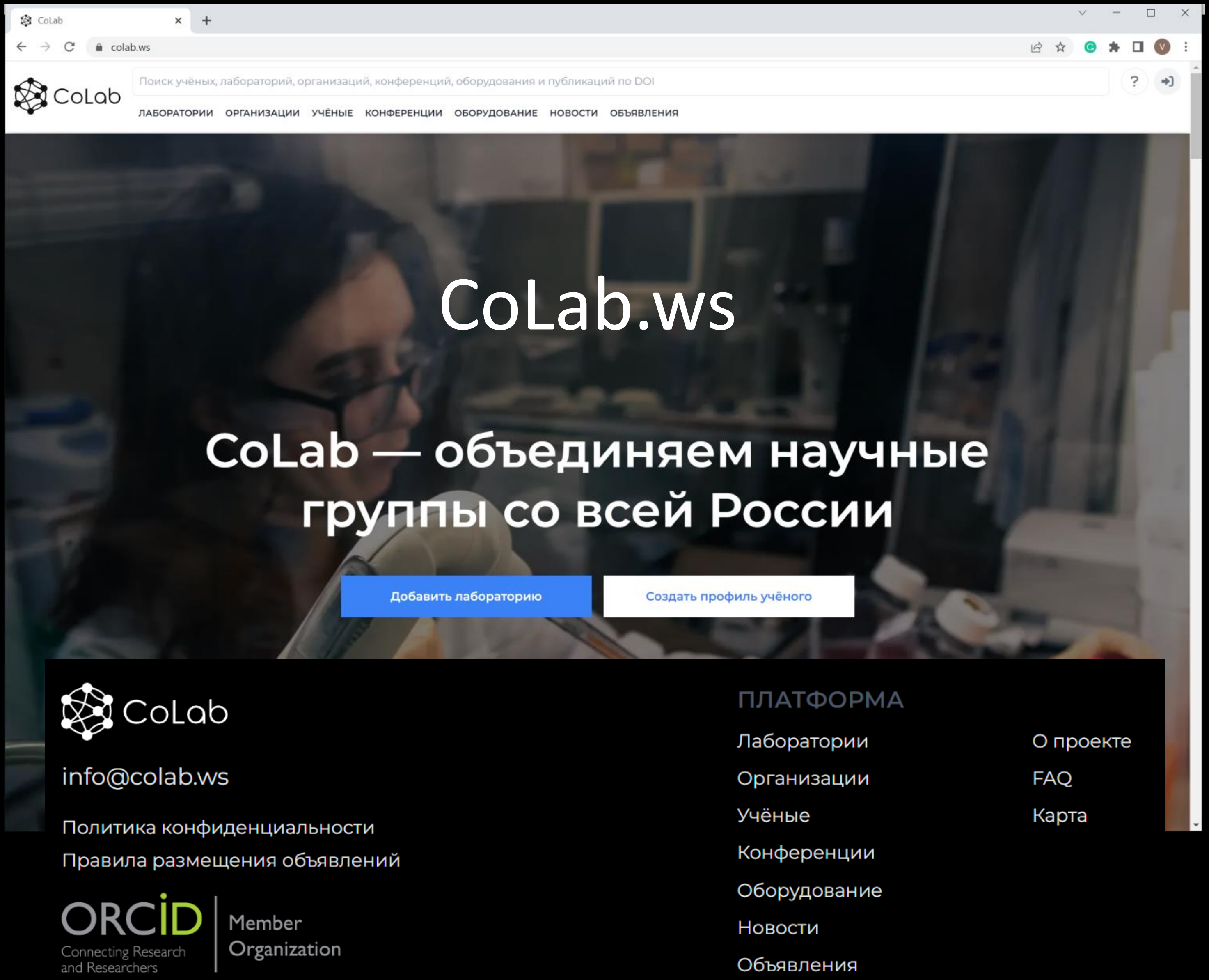
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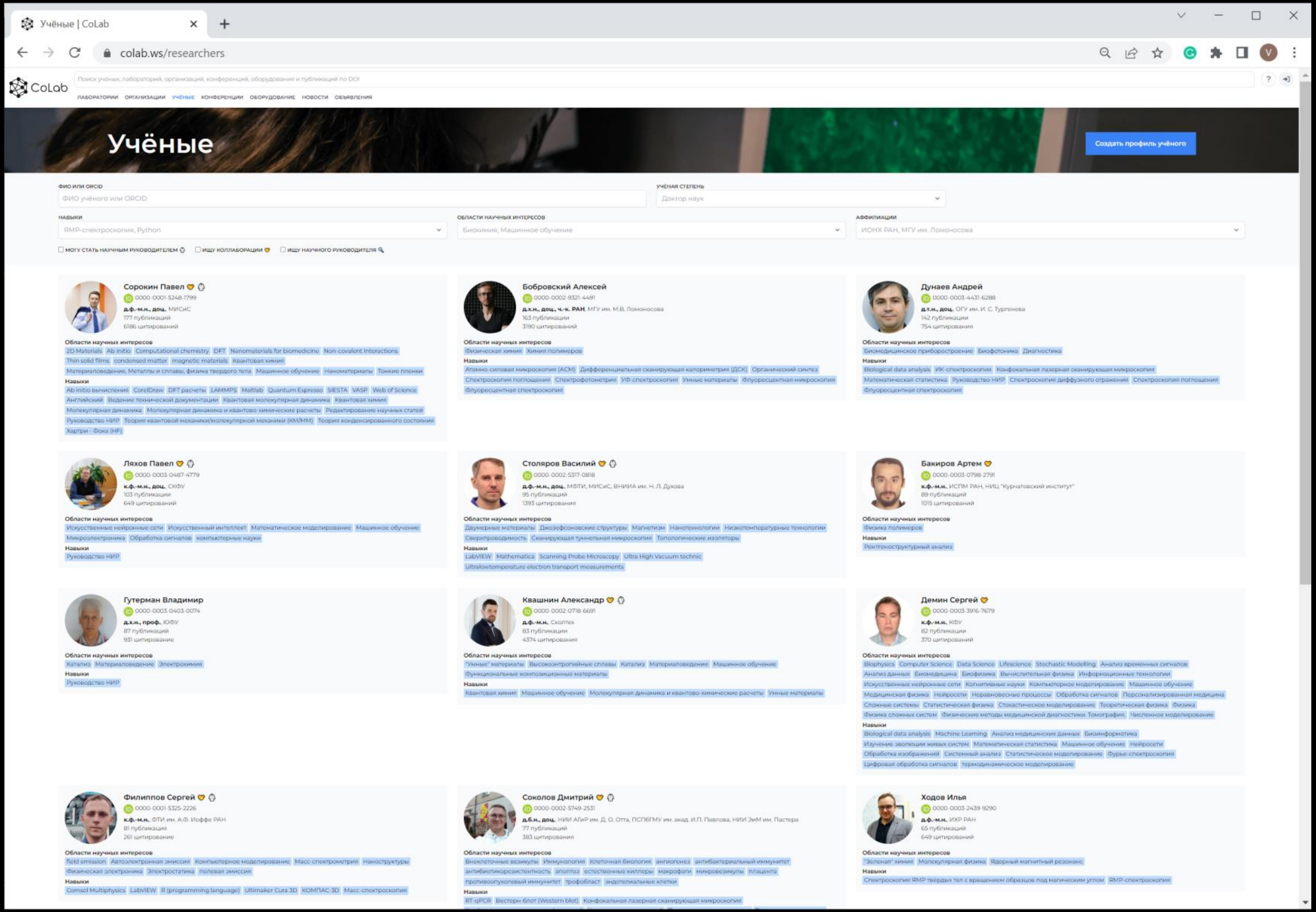
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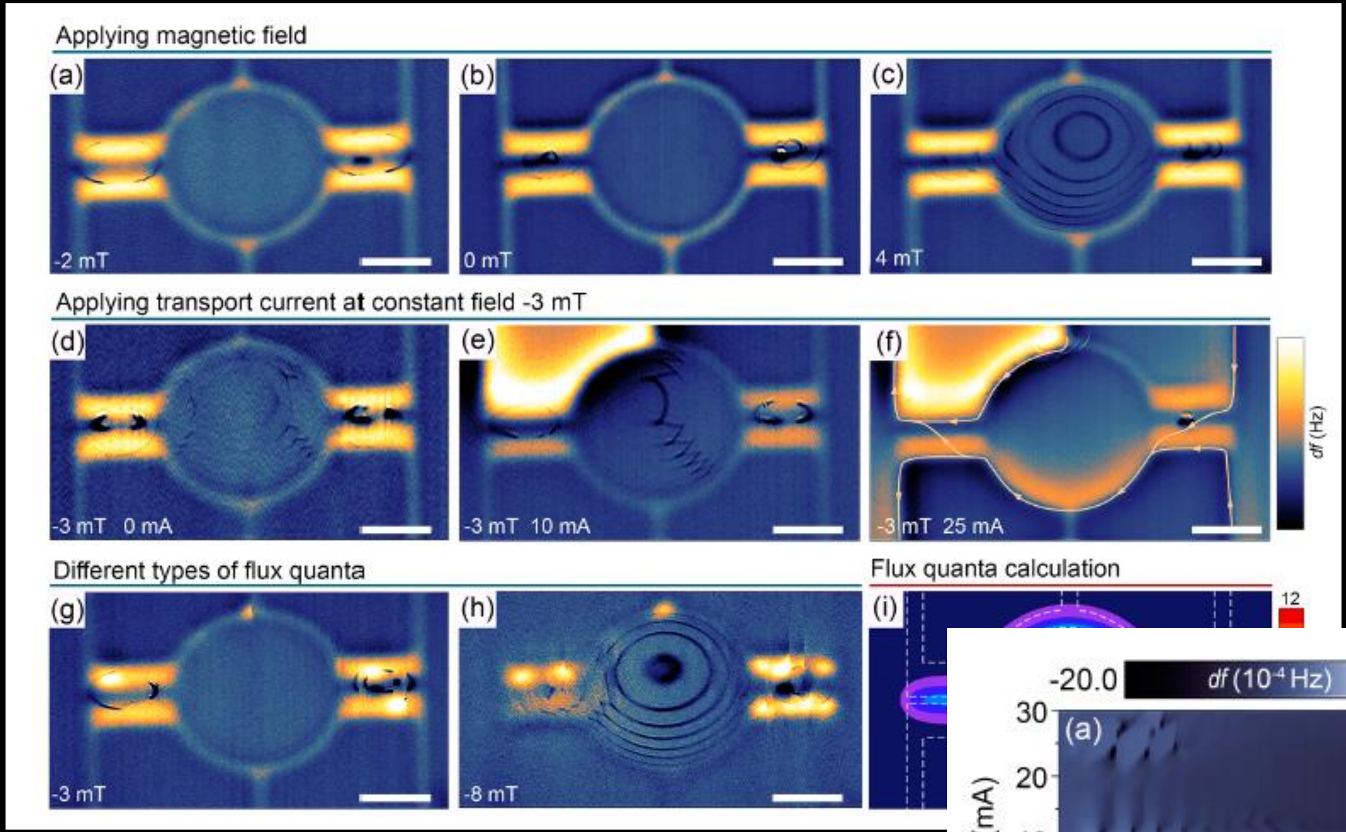
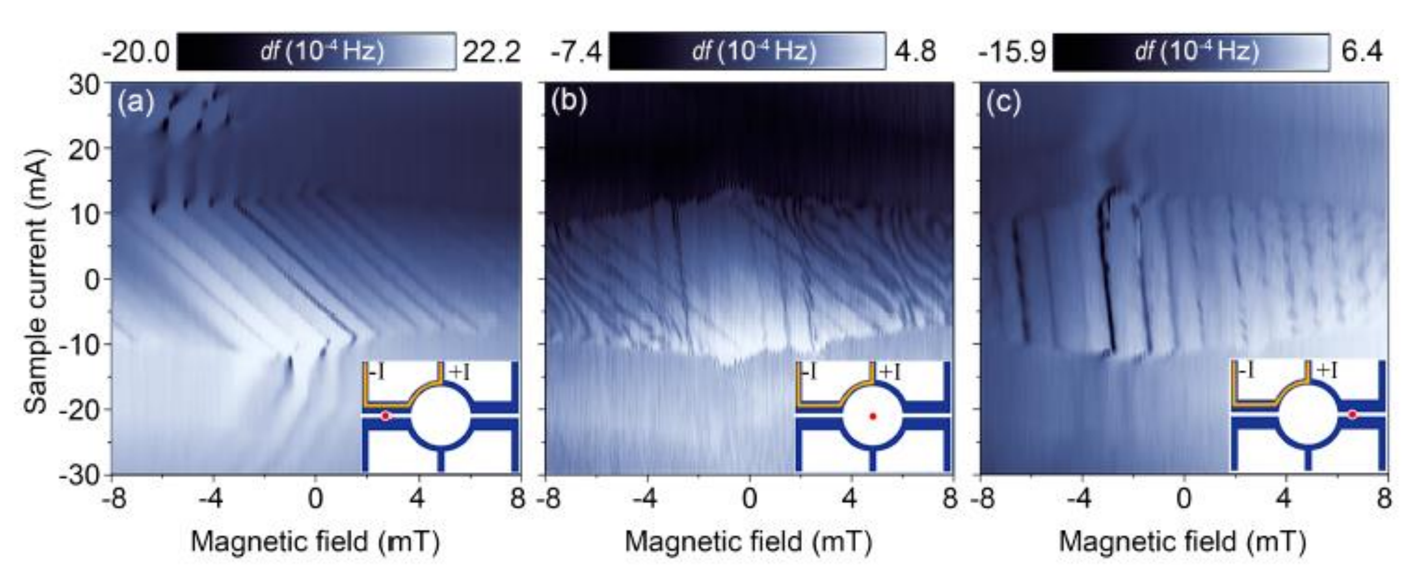


Applying magnetic field
(a)
-2 mT
(b)
0 mT
(c)
4 mT
Applying transport current at constant field -3 mT
(d)
-3 mT 0 mA
(e)
-3 mT 10 mA
(f)
-3 mT 25 mA
df (Hz)
Different types of flux quanta
(g)
-3 mT
(h)
-8 mT
Flux quanta calculation
(i)
12



-20.0
df (10⁻⁴ Hz)
22.2
-7.4
df (10⁻⁴ Hz)
4.8
-15.9
df (10⁻⁴ Hz)
6.4
Sample current (mA)
(a)
(b)
(c)
-I
+I
Magnetic field (mT)