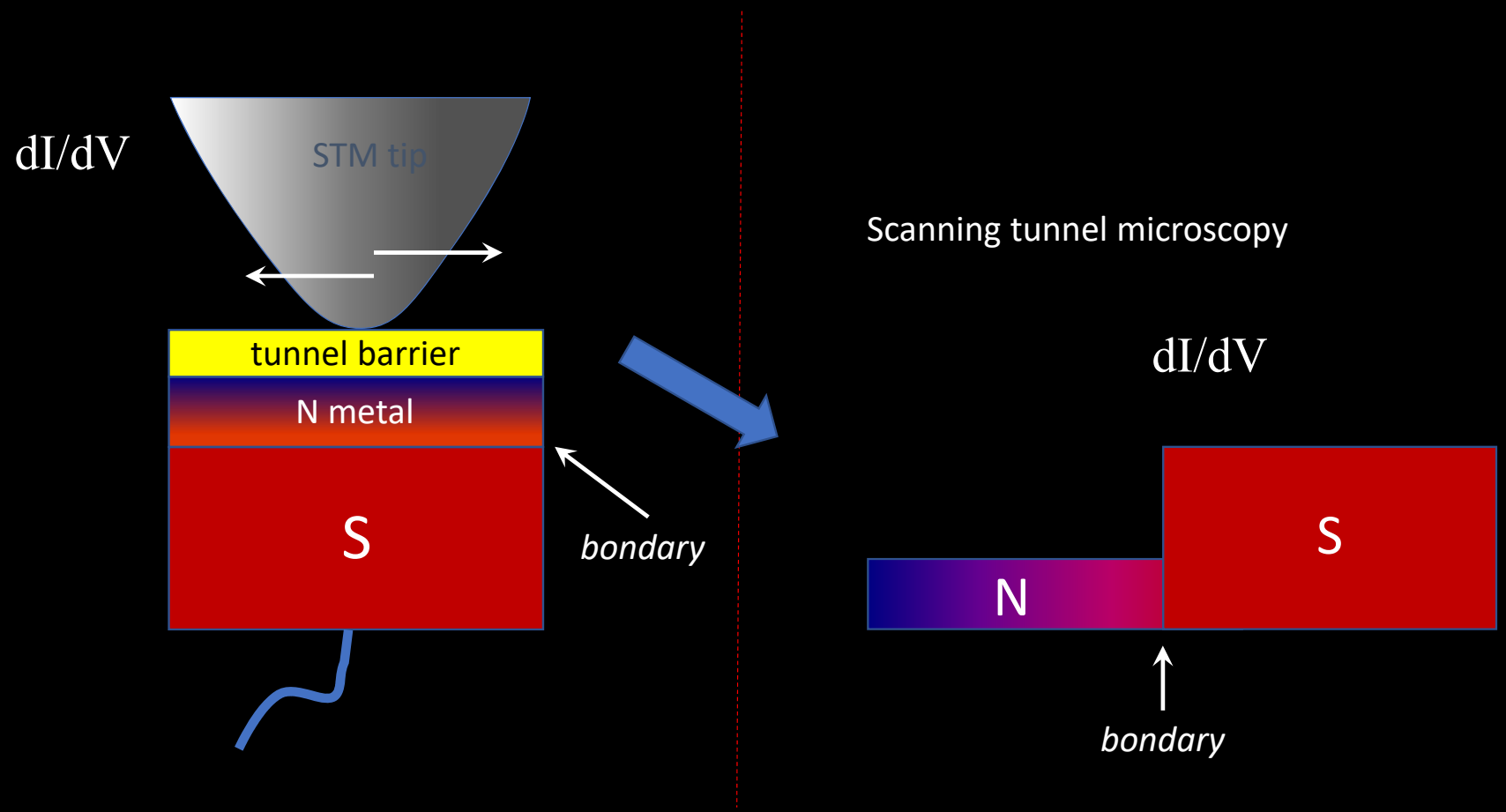


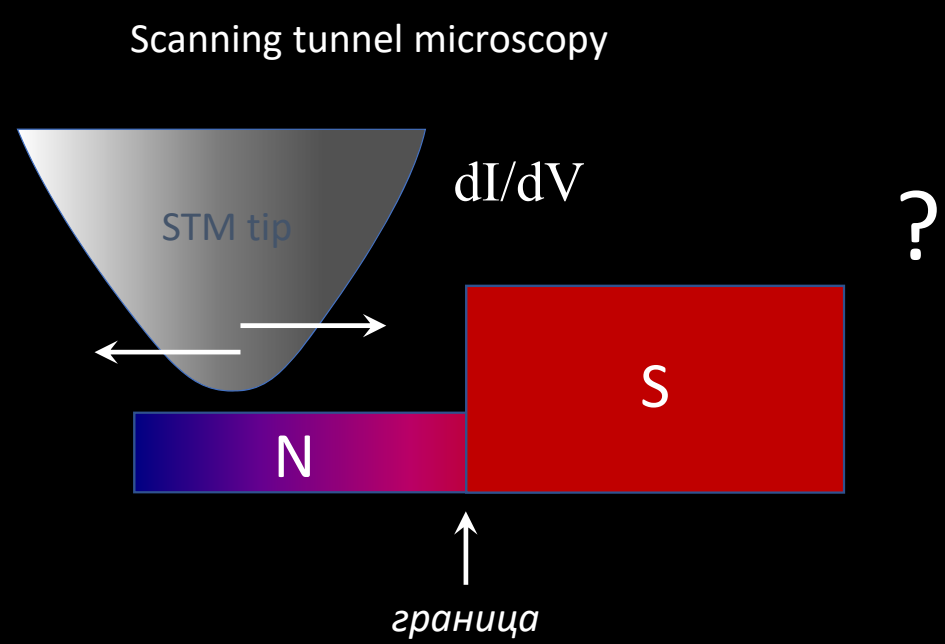
Cryogenic Atomic Force Microscopy

Lecture 2

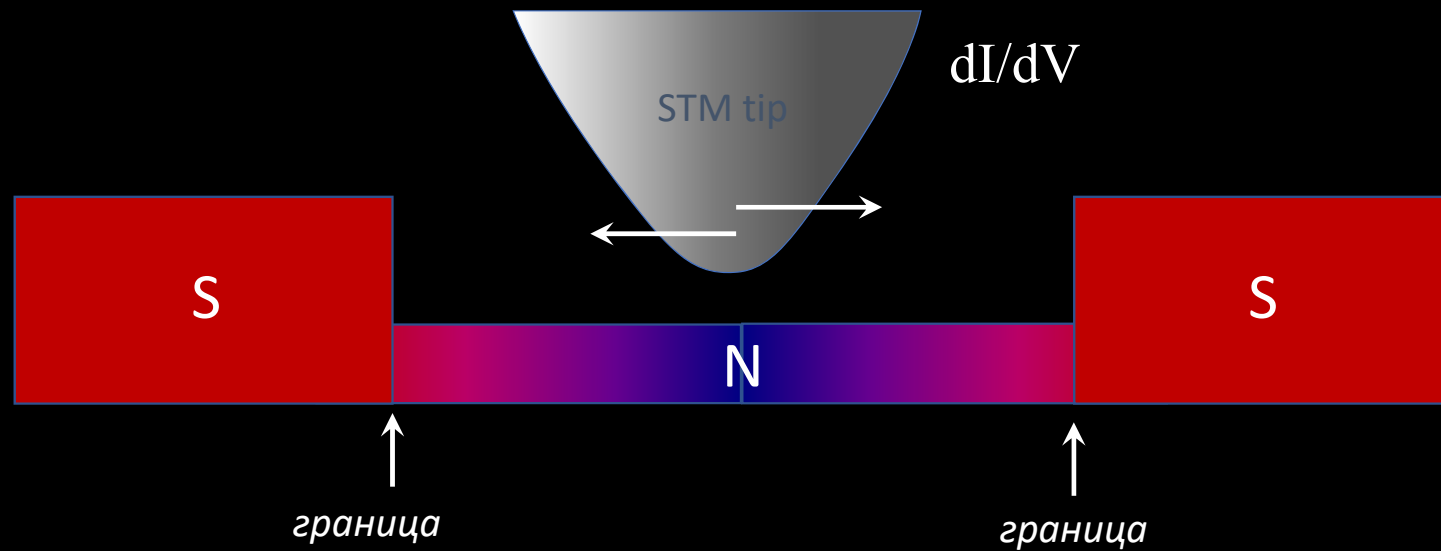
Josephson vortex: direct observation



Josephson vortex: direct observation



Scanning tunnel microscopy





Josephson vortex: direct observation



LETTERS

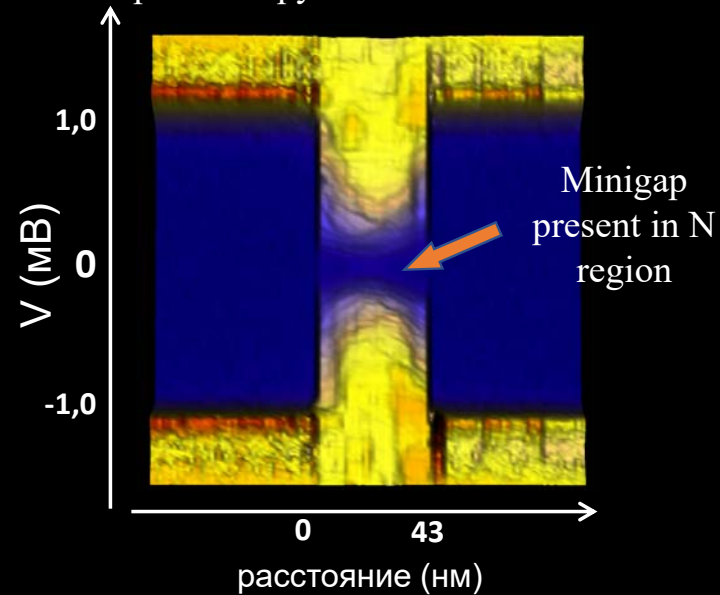
PUBLISHED ONLINE: 23 FEBRUARY 2015 | DOI: 10.1038/NPHYS3240

nature
physics

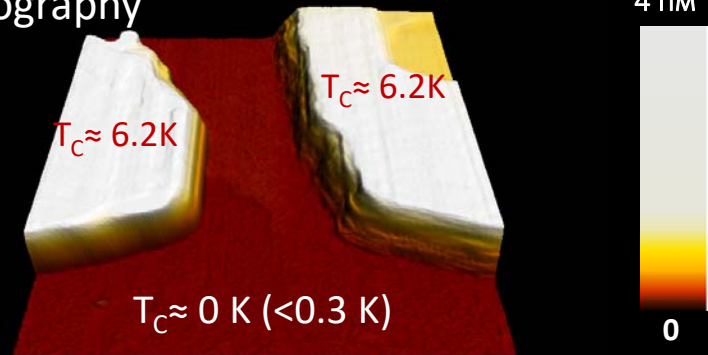
Direct observation of Josephson vortex cores

Dimitri Roditchev^{1,2}, Christophe Brun¹, Lise Serrier-Garcia¹, Juan Carlos Cuevas³,
Vagner Henrique Loiola Bessa⁴, Milorad Vlado Milošević^{4,5}, François Debontridder¹,
Vasily Stolyarov¹ and Tristan Cren^{1*}

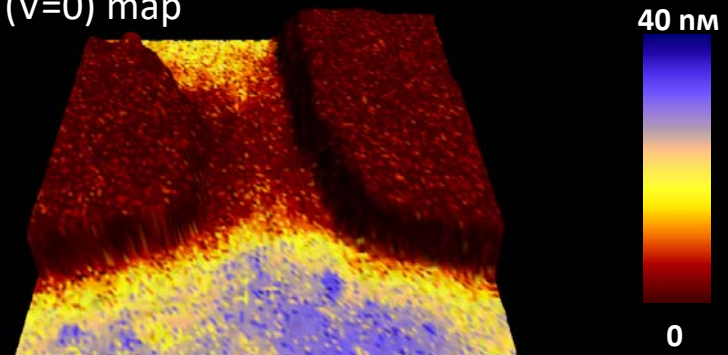
dI/dV- spectroscopy in linear distribution



topography



STS ($V=0$) map





Josephson vortex: direct observation



LETTERS

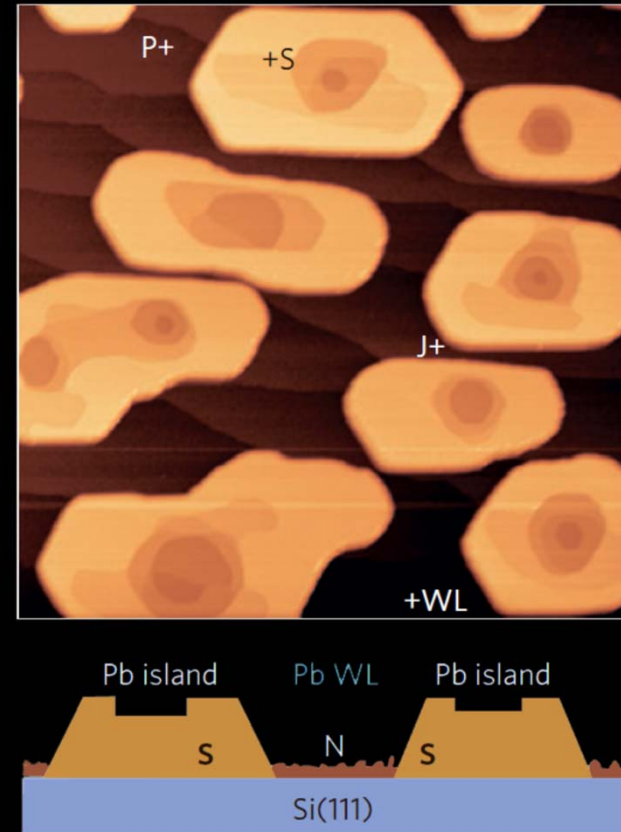
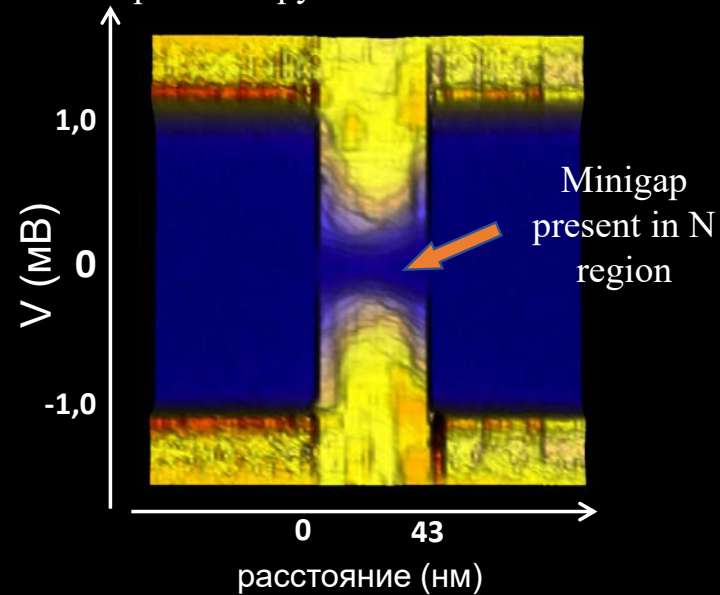
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Vasily Stolyarov¹ and Tristan Cren^{1*}

dI/dV - spectroscopy in linear distribution





Josephson vortex: direct observation



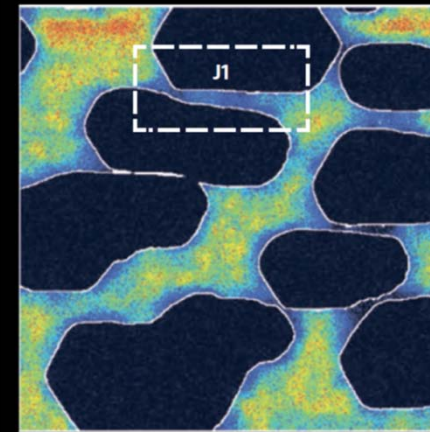
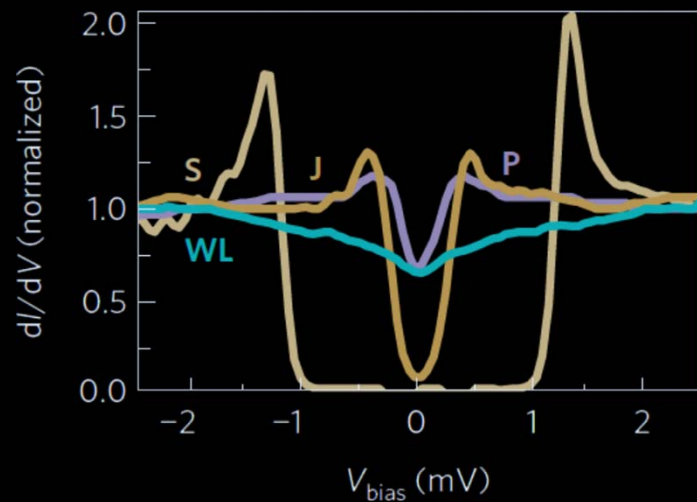
LETTERS

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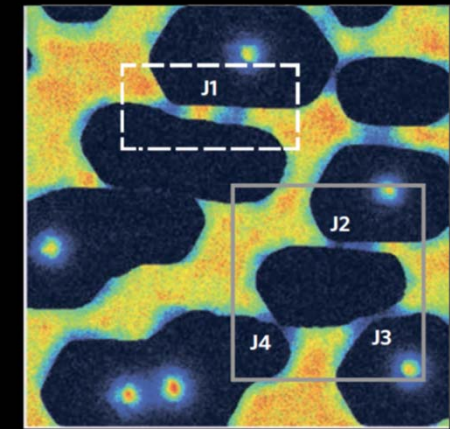
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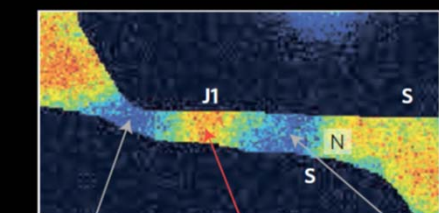
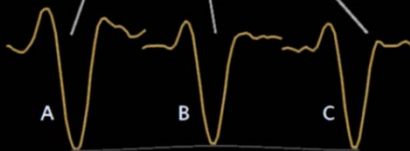
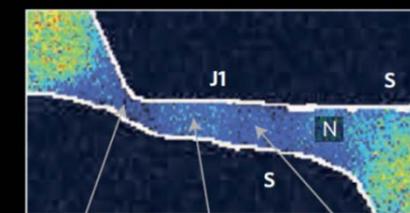
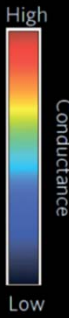


0 mT



60 mT

⊙ H





Josephson vortex: direct observation



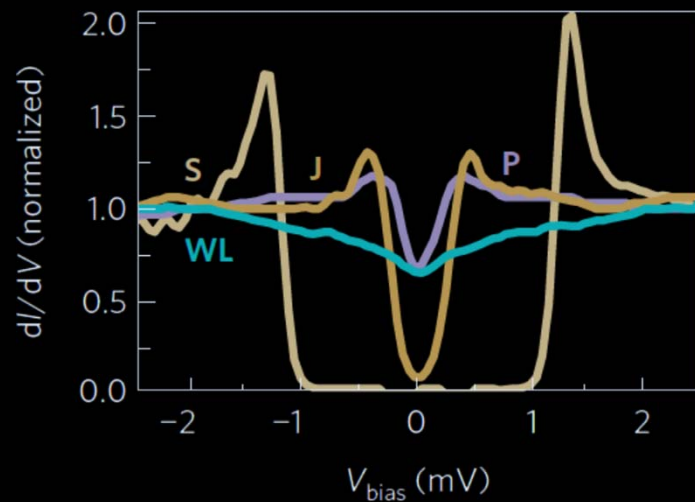
LETTERS

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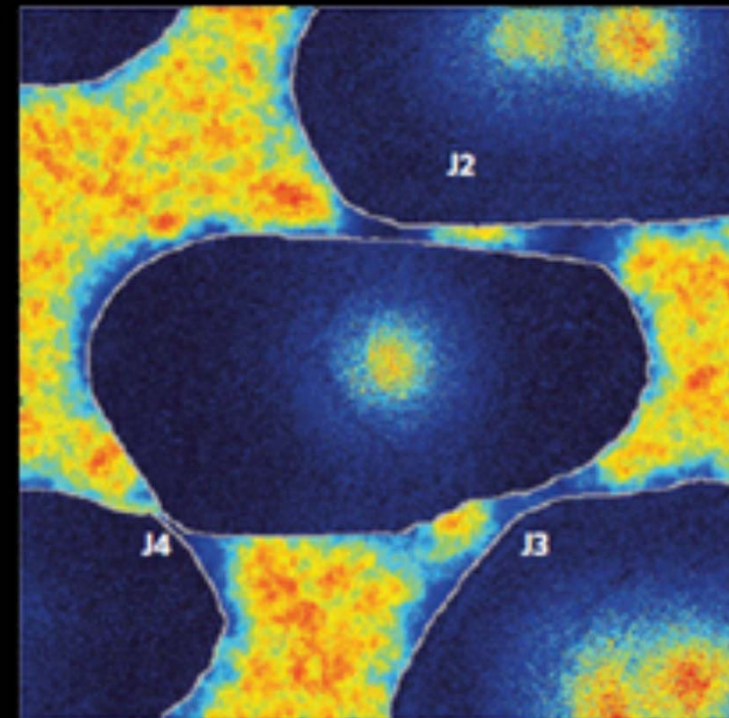
nature
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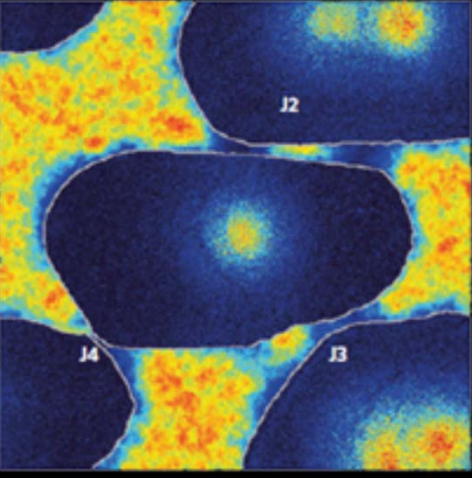
120 mT



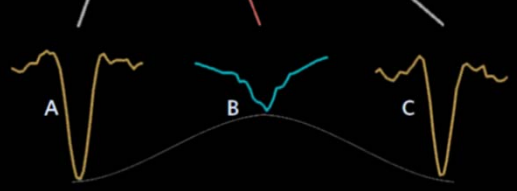
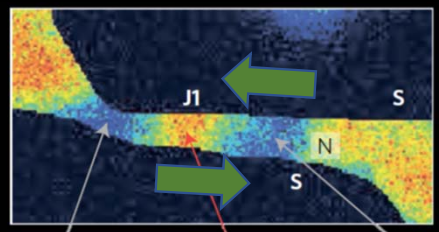
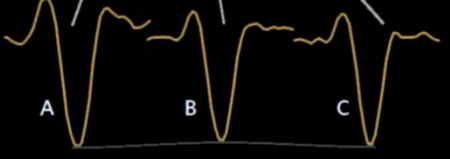
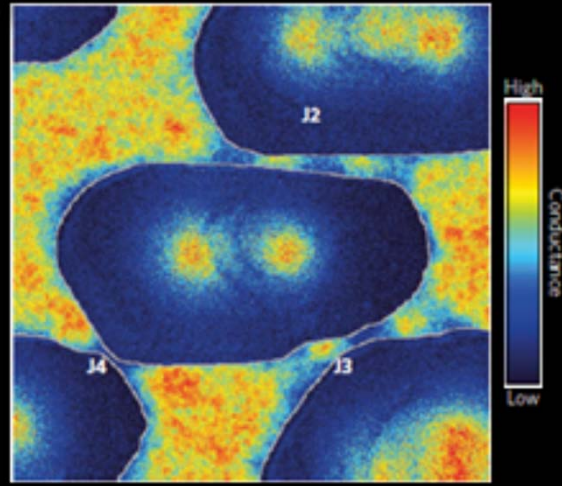


Josephson vortex: direct observation

120 mT



180 mT

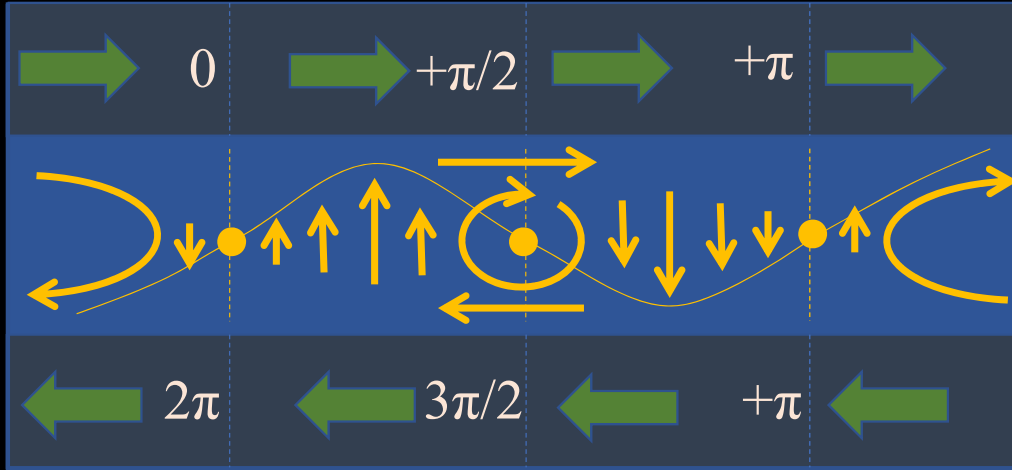
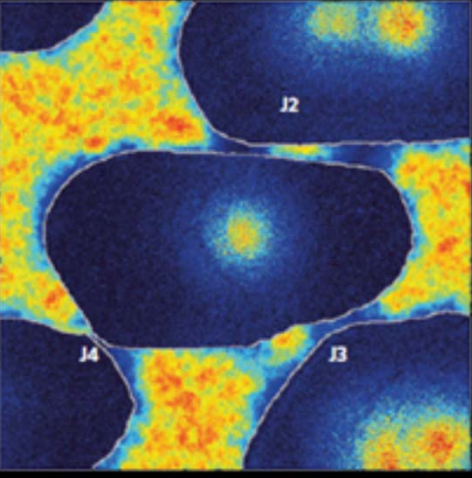




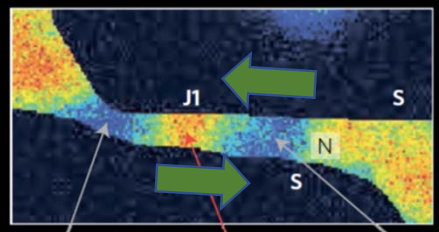
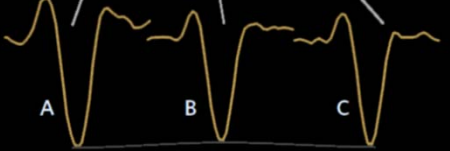
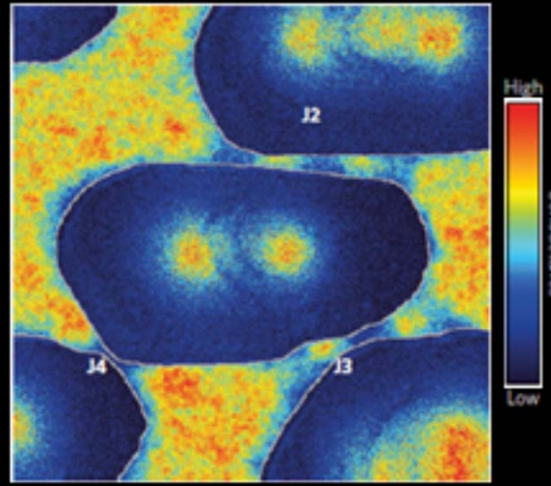
Josephson vortex: direct observation



120 mT

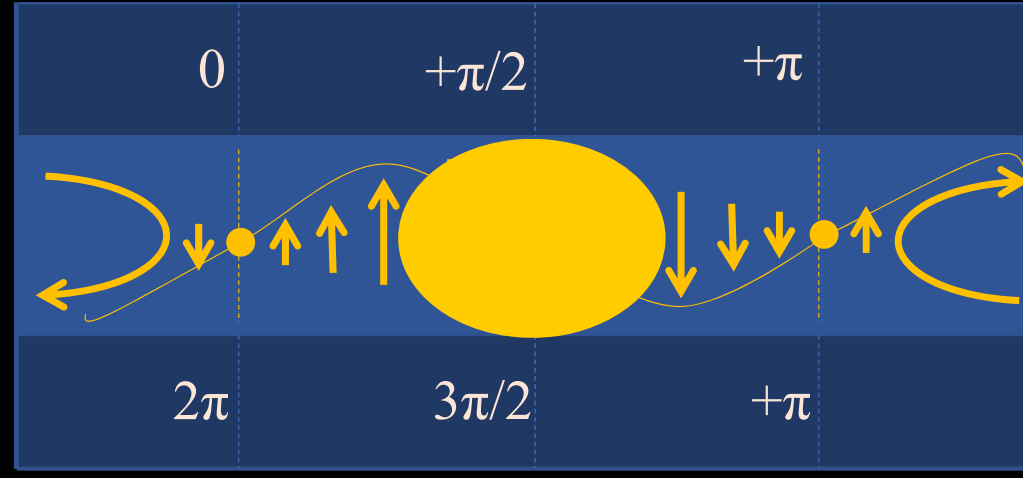
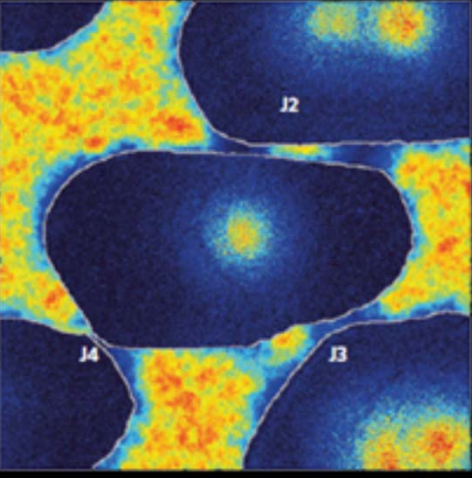


180 mT

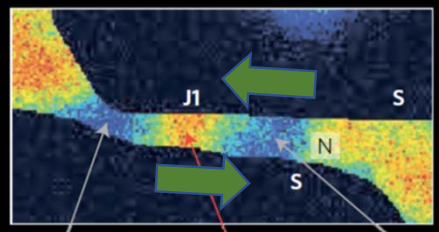
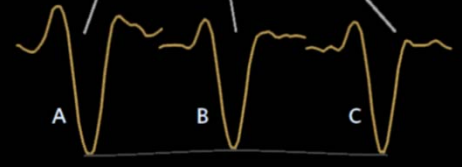
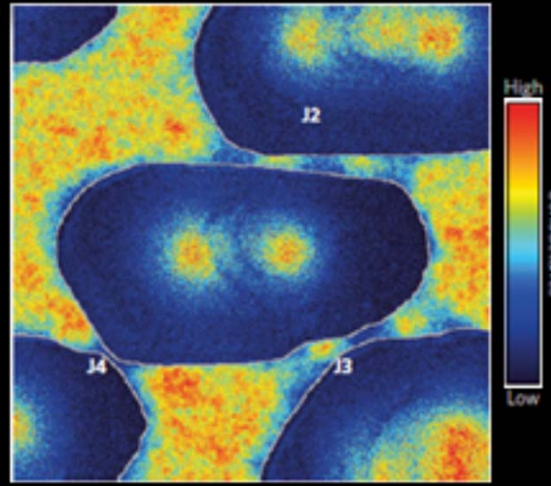


Josephson vortex: direct observation

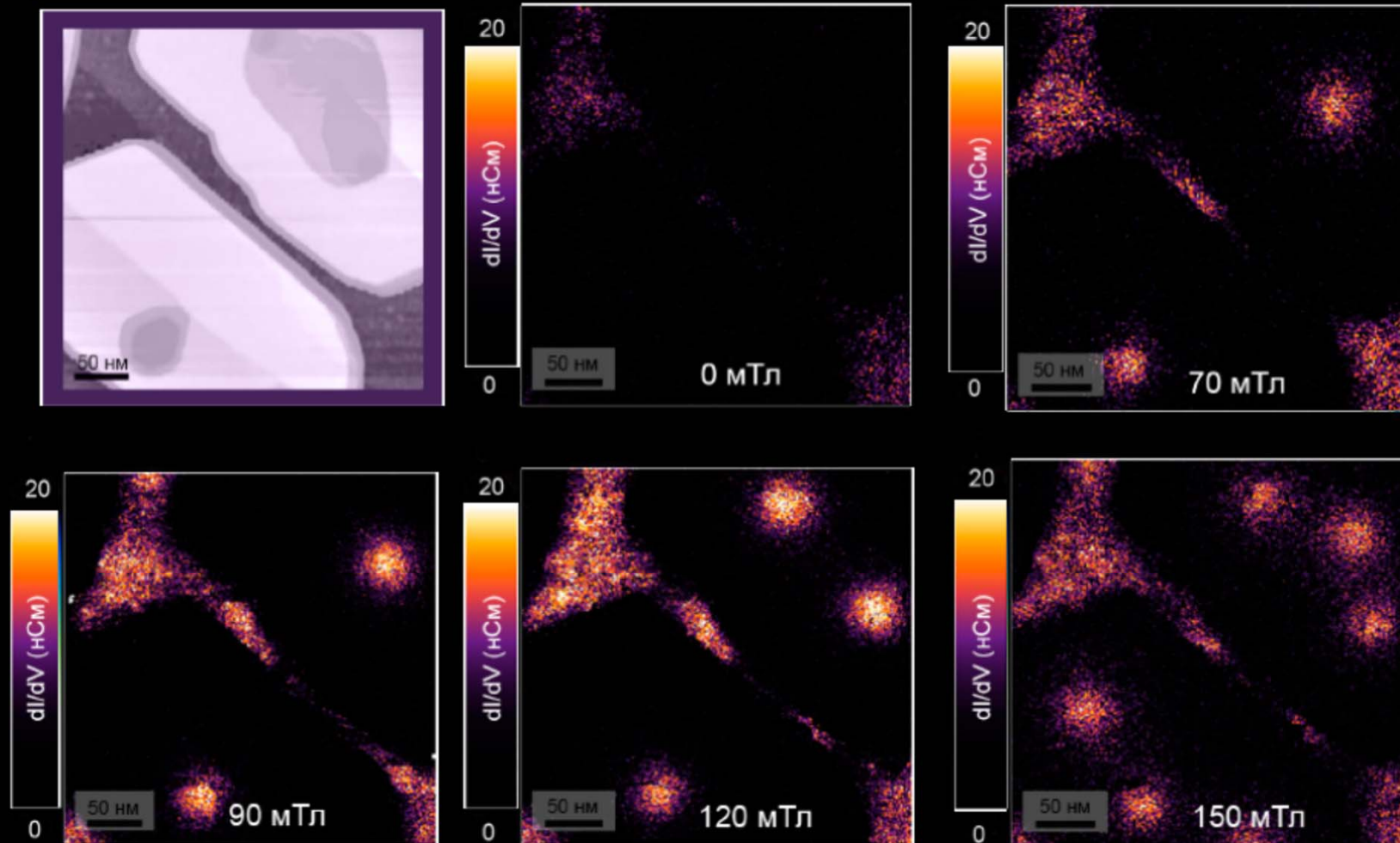
120 mT



180 mT

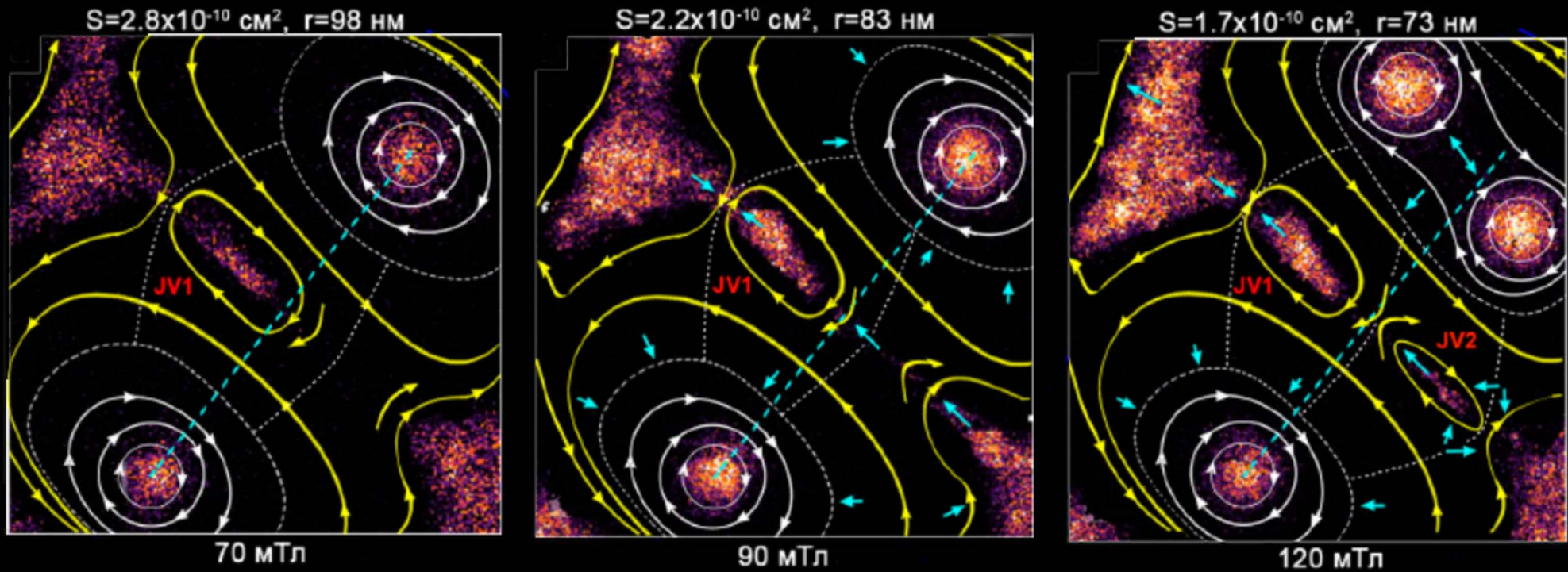


Josephson vortex: direct observation



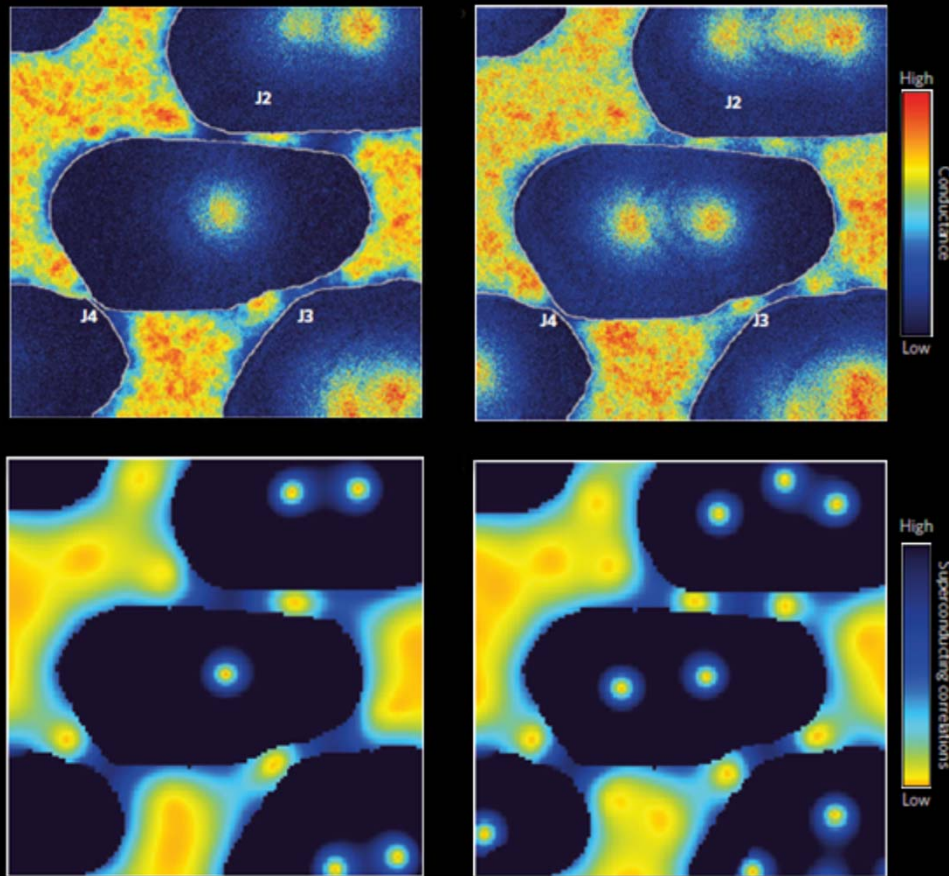


Вихрь Джозефсона: прямое наблюдение

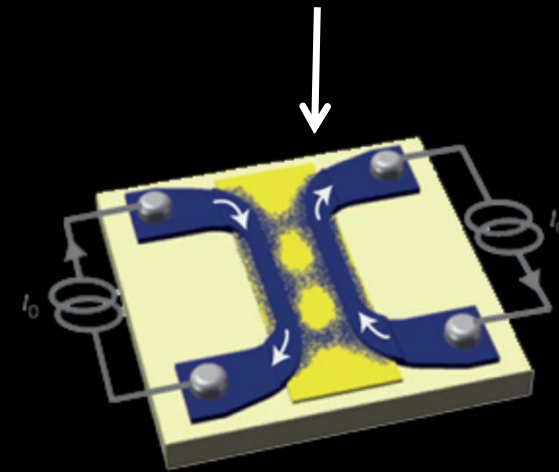




Josephson vortex: direct observation



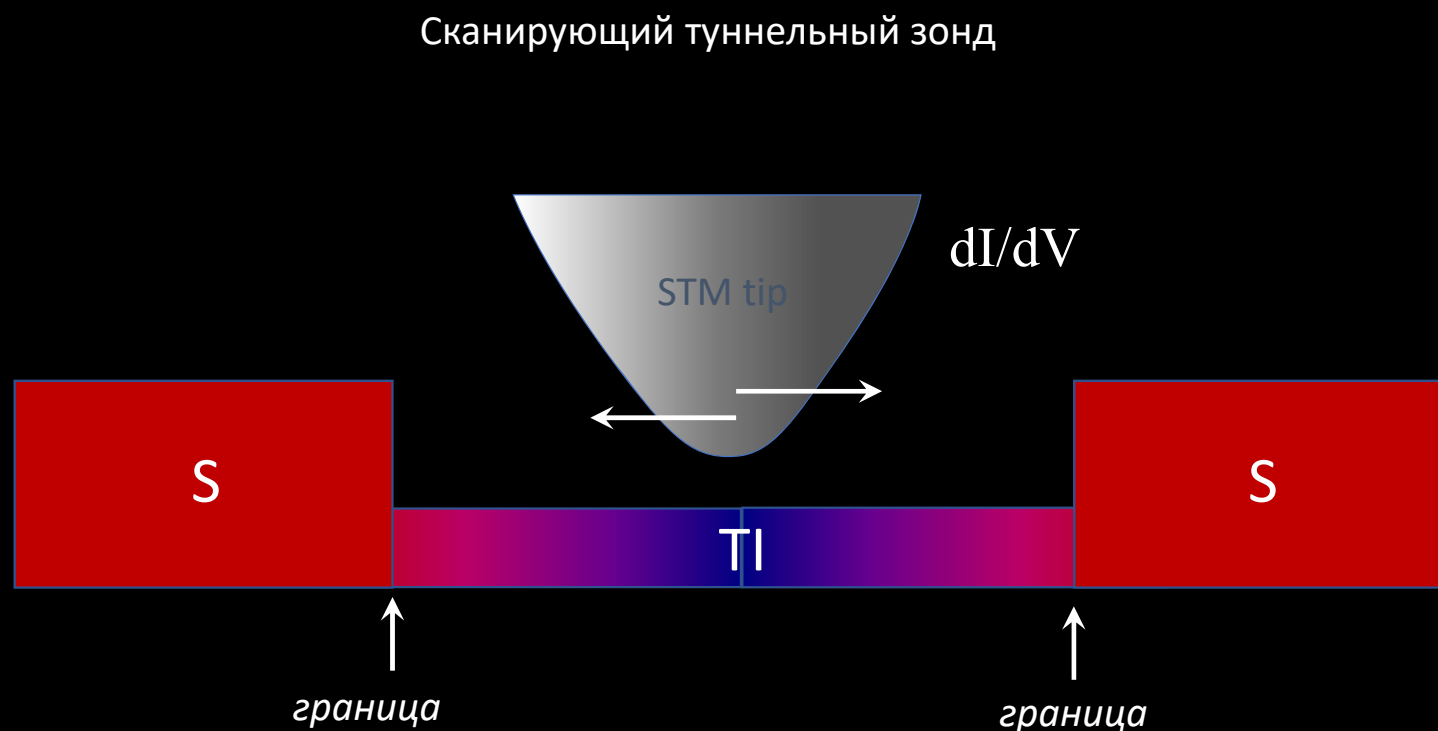
Suggested logical device



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

Глава 4

Эффект близости через атомно-плоский интерфейс топологического изолятора



Глава 4 Эффект близости через атомно-плоский интерфейс топологического изолятора

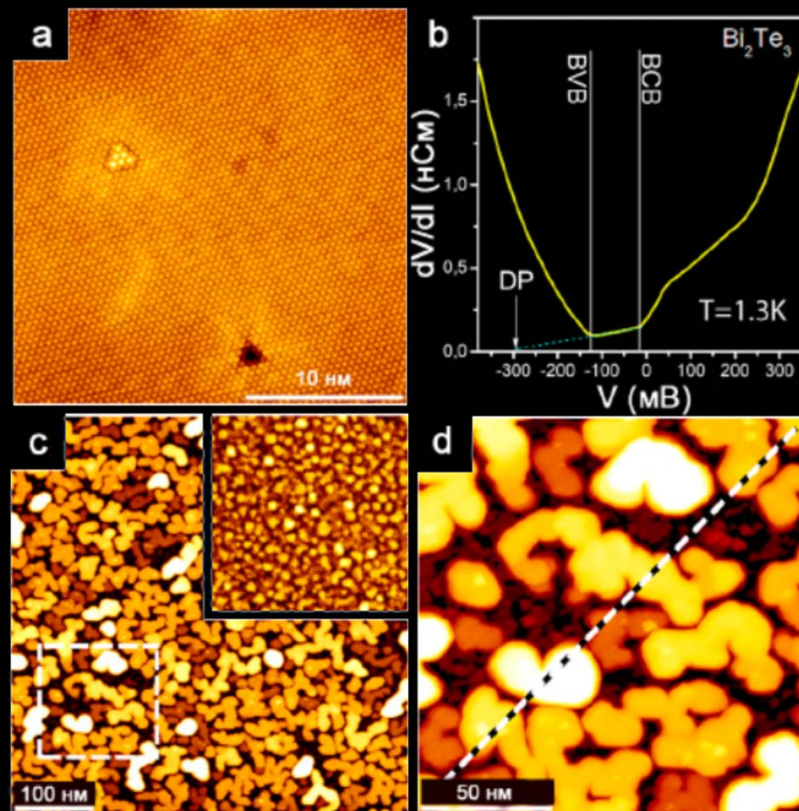
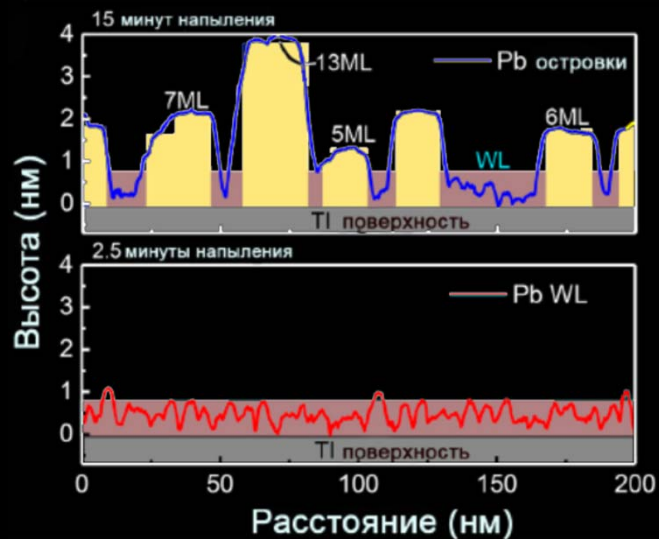
THE JOURNAL OF
PHYSICAL CHEMISTRY
LETTERS
A JOURNAL OF THE AMERICAN CHEMICAL SOCIETY

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Letter

Superconducting Long-Range Proximity Effect through the Atomically Flat Interface of a Bi_2Te_3 Topological Insulator

Vasily S. Stolyarov,* Stephane Pons, Sergio Vlaic, Sergey V. Remizov, Dmitriy S. Shapiro, Christophe Brun, Sergey I. Bozhko, Tristan Cren, Tatiana V. Menshchikova, Evgueni V. Chulkov, Walter V. Pogosov, Yuriy E. Lozovik, and Dimitri Roditchev



Глава 4 Эффект близости через атомно-плоский интерфейс ТОПОЛОГИЧЕСКОГО ИЗОЛЯТОРА

THE JOURNAL OF
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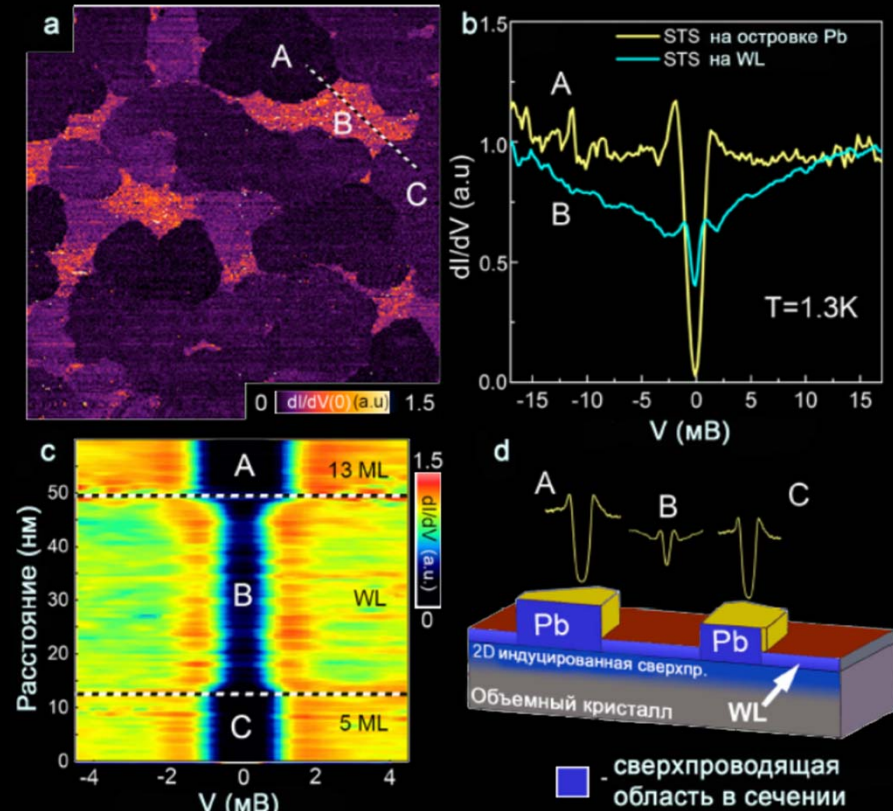
Letter

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$$\xi = \frac{\hbar v_F}{\Delta_{TI}}$$

$$\xi \sim 0.7 \text{ мкм}$$



Глава 4 Эффект близости через атомно-плоский интерфейс ТОПОЛОГИЧЕСКОГО ИЗОЛЯТОРА

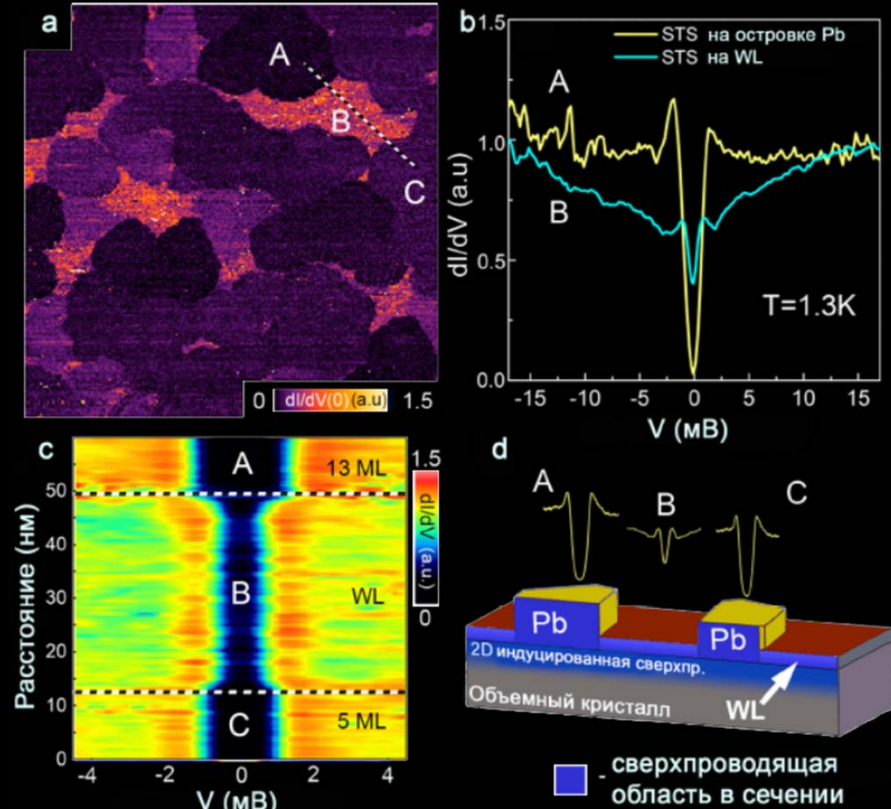
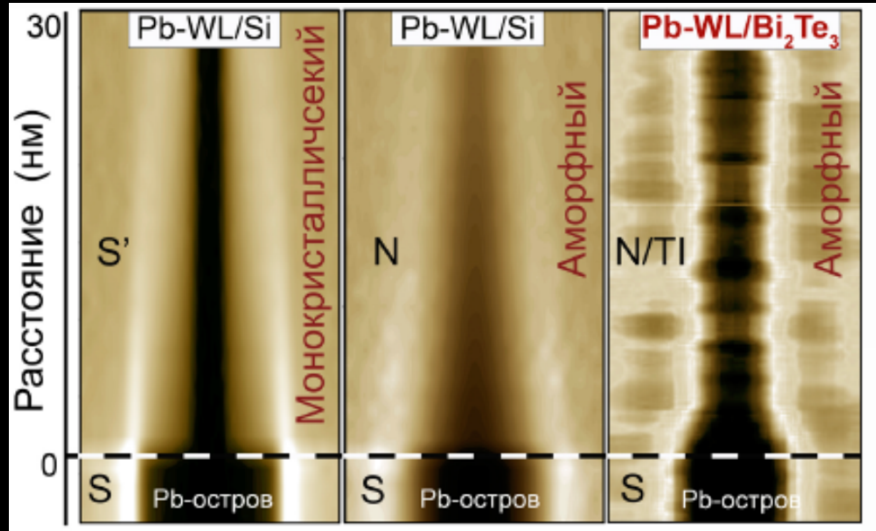
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Letter

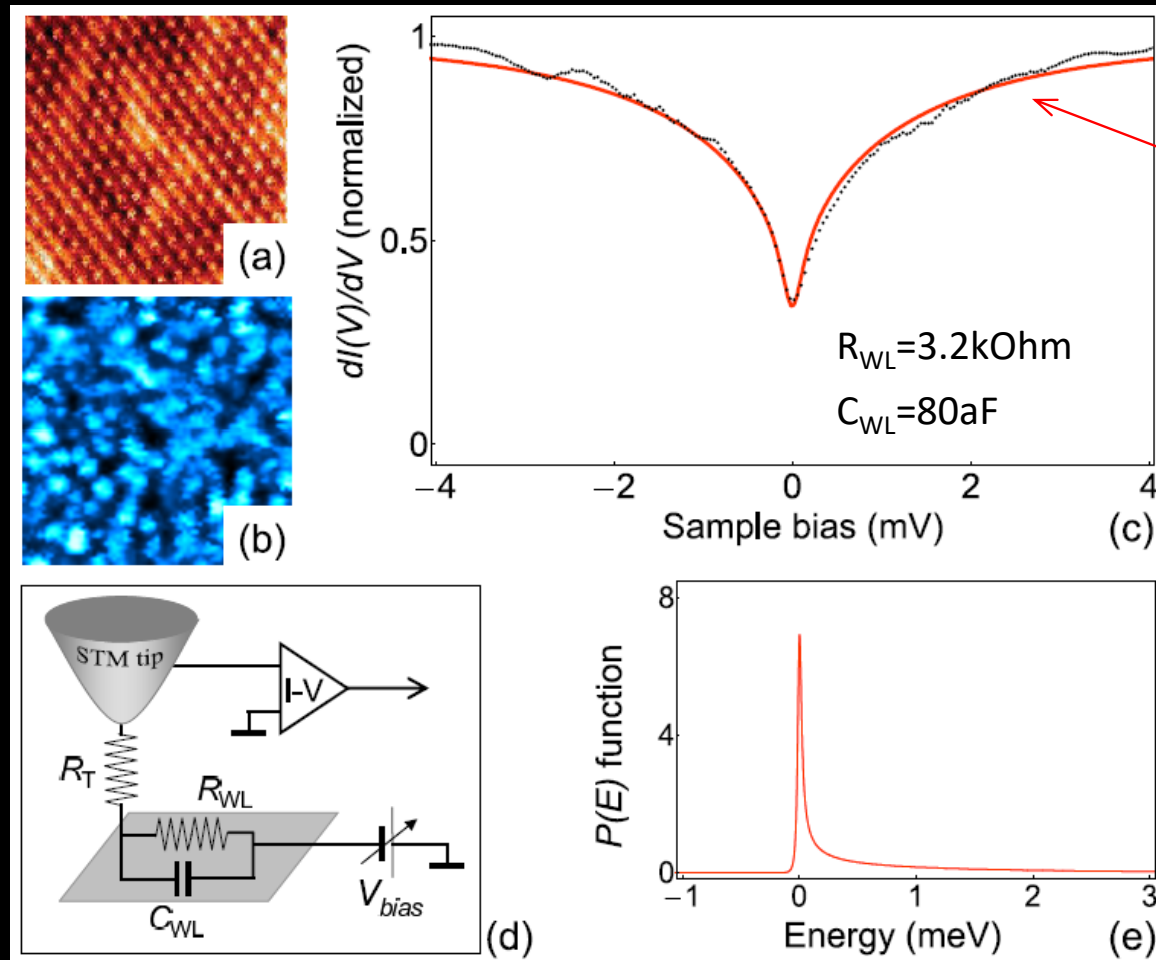
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Josephson vortex matter in lateral proximity junctions

2.3. S-N: Lateral proximity effect in a disordered metal



DCB fit

Глава 4

Резонансные осцилляции критического тока джозефсоновских контактов на основе топологических изоляторов

ARTICLE
<https://doi.org/10.1038/s43246-020-0037-y> OPEN



Josephson current mediated by ballistic topological states in $\text{Bi}_2\text{Te}_{2.3}\text{Se}_{0.7}$ single nanocrystals

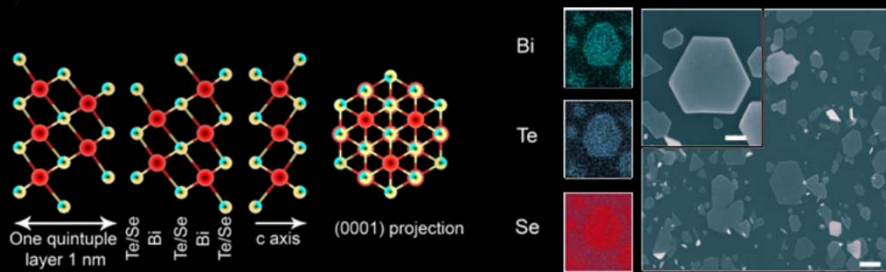
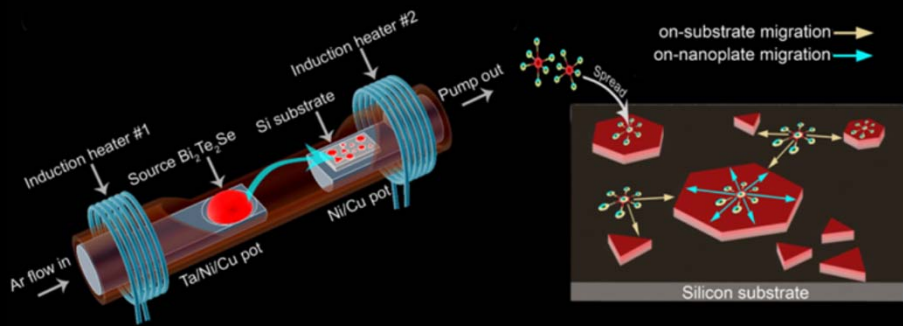
Vasily S. Stolyarov^{1,2,3,4,8*}, Dmitry S. Yakovlev^{1,5,6}, Sergei N. Kozlov^{1,2,7,8}, Olga V. Skryabina^{1,5}, Dmitry S. Lvov⁵, Amir I. Gumarov⁴, Olga V. Emelyanova⁹, Pavel S. Dzhumaev⁹, Igor V. Shchetinin¹⁰, Razmik A. Hovhannisyian¹, Sergey V. Egorov^{5,6}, Andrey M. Kokotin⁵, Walter V. Pogosov^{1,3}, Valery V. Ryazanov⁵, Mikhail Yu. Kupriyanov^{4,11}, Alexander A. Golubov^{1,12} & Dimitri Roditchev^{1,8,13}

RESEARCH ARTICLE

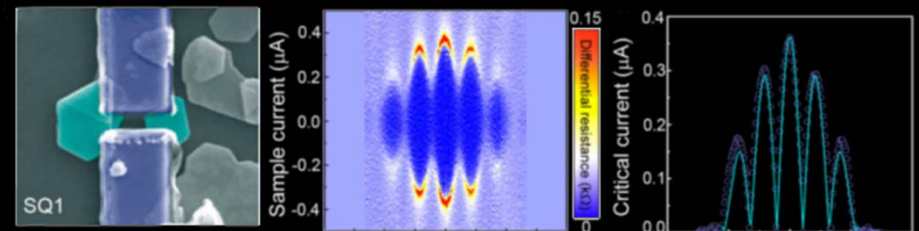
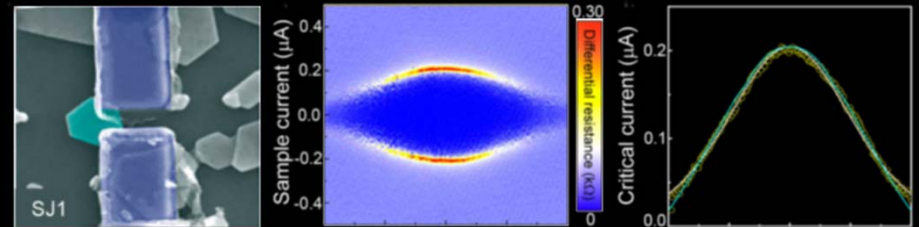
ADVANCED QUANTUM TECHNOLOGIES
 www.advquantumtech.com

Resonant Oscillations of Josephson Current in $\text{Nb-Bi}_2\text{Te}_{2.3}\text{Se}_{0.7}\text{-Nb}$ Junctions

Vasily S. Stolyarov,* Dimitri Roditchev, Vladimir L. Gurtovoi, Sergey N. Kozlov, Dmitry S. Yakovlev, Olga V. Skryabina, Valerii M. Vinokur, and Alexander A. Golubov



$T=700$ мК

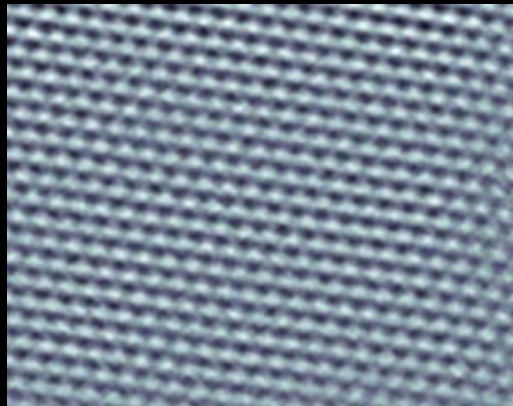
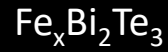


Cryogenic Magnetic Force Microscopy

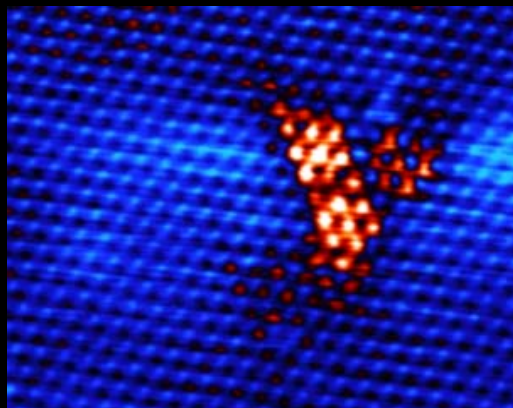


STM & MFM

МФТИ

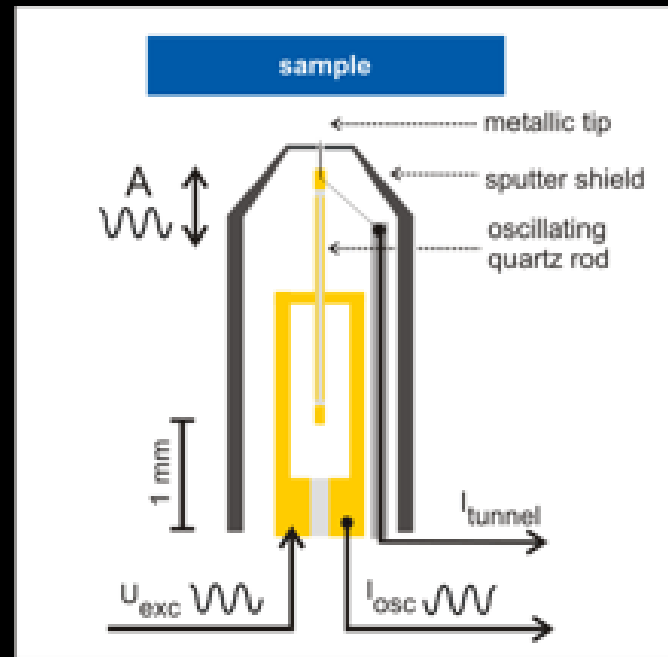


топография AFM



Торография STM

Scanning probe microscopy from STM to AFM



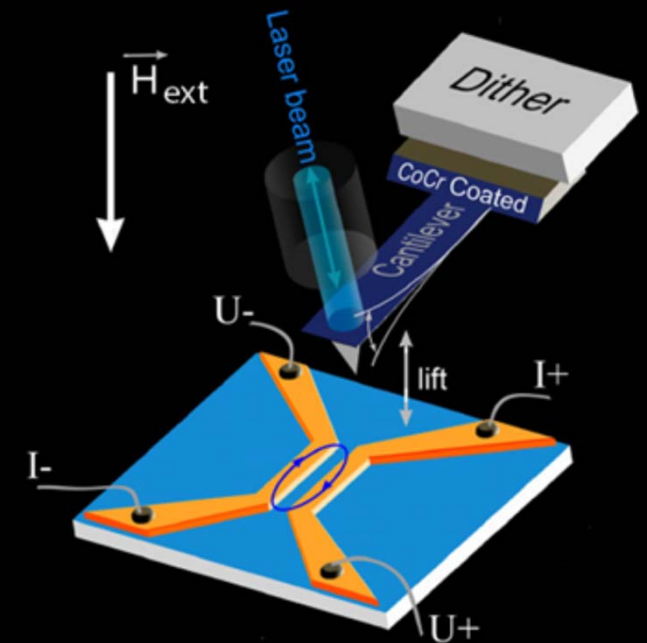
APPLIED PHYSICS LETTERS 111, 251601 (2017)



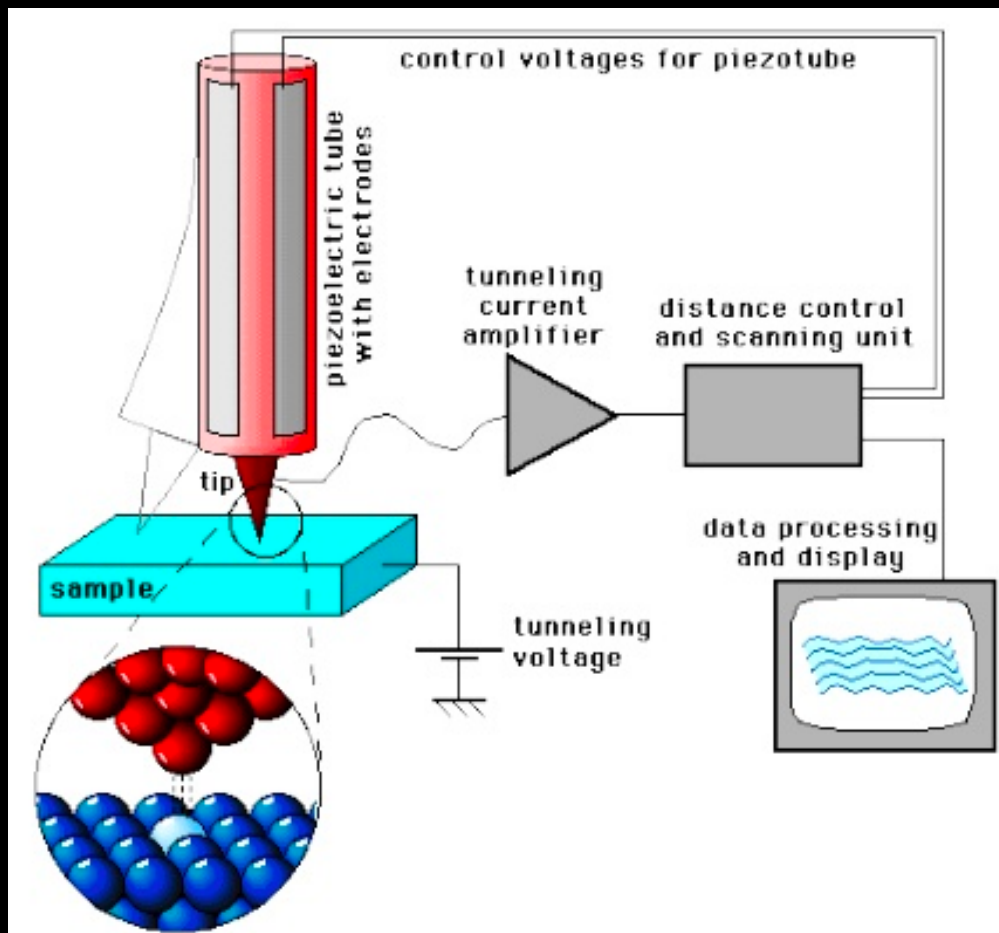
Double Fe-impurity charge state in the topological insulator Bi_2Se_3

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}

¹Laboratoire de Physique et d'Etudes des Matériaux, ESPCI-Paris, CNRS and UPMC Univ Paris 6-UMR 8213, 10 rue Vauquelin, 75005 Paris, France



Scanning Tunneling Microscope

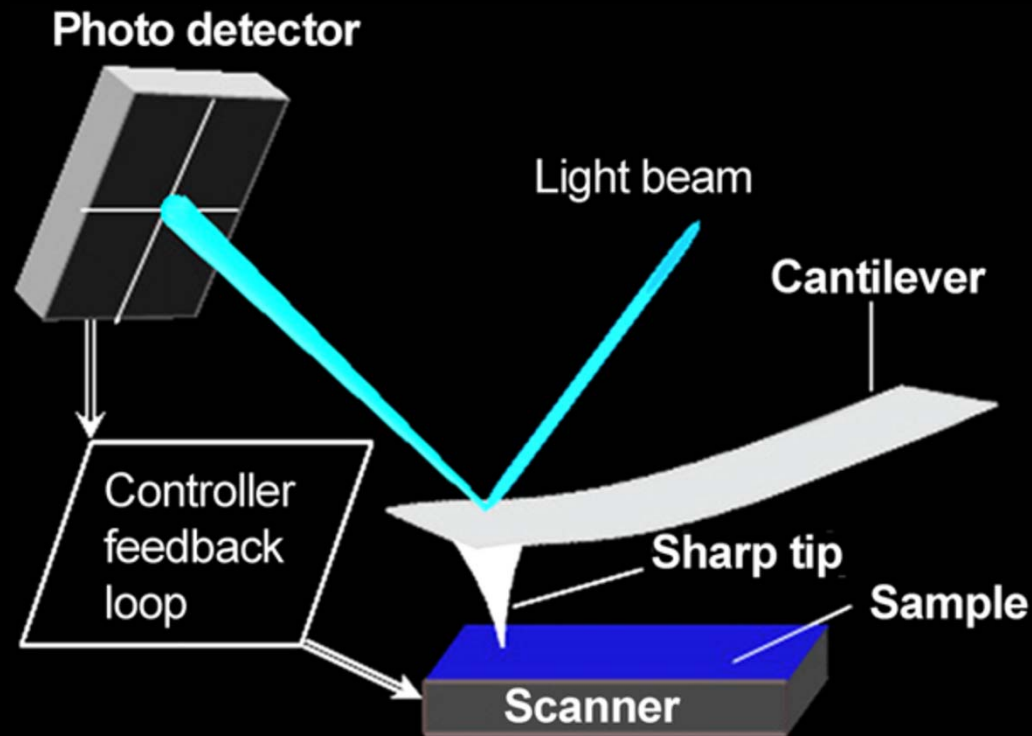


- ✓ **STM - what is measured:**
the tunneling current
between a metallic tip and
a conducting sample



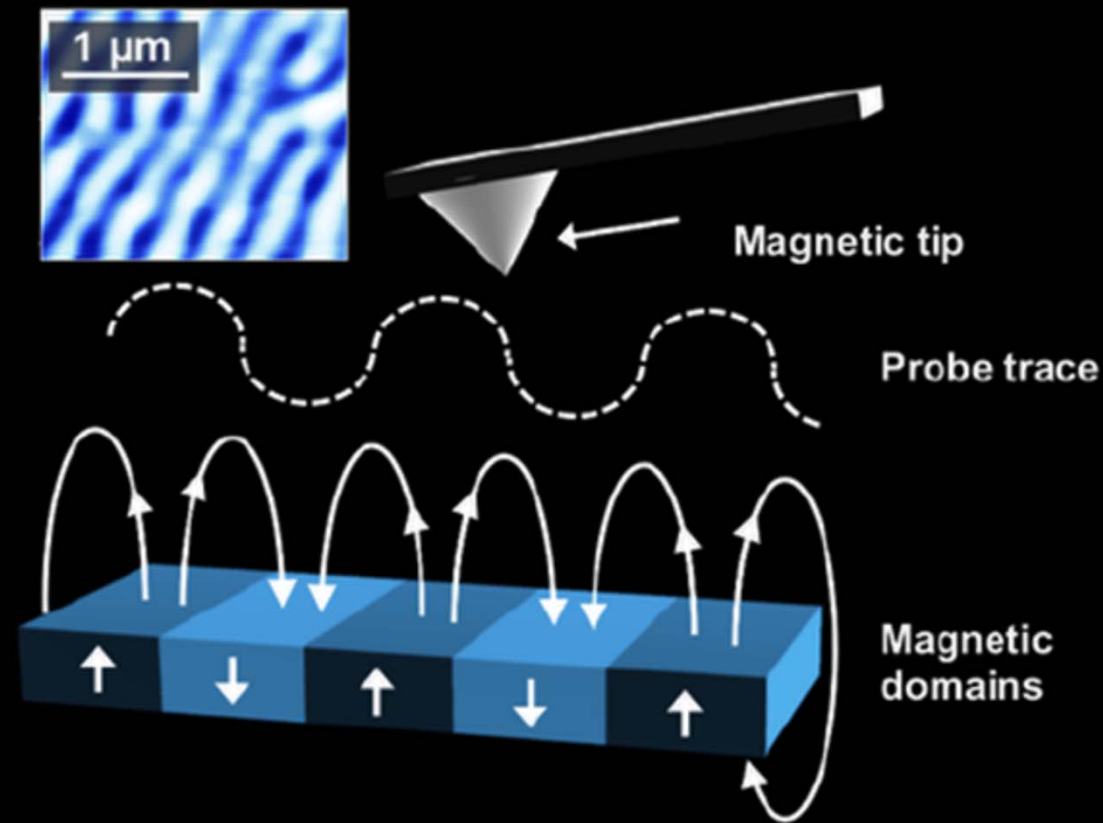
Investigation of the dynamics of Josephson vortices using a magnetic force microscope

- ✓ 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



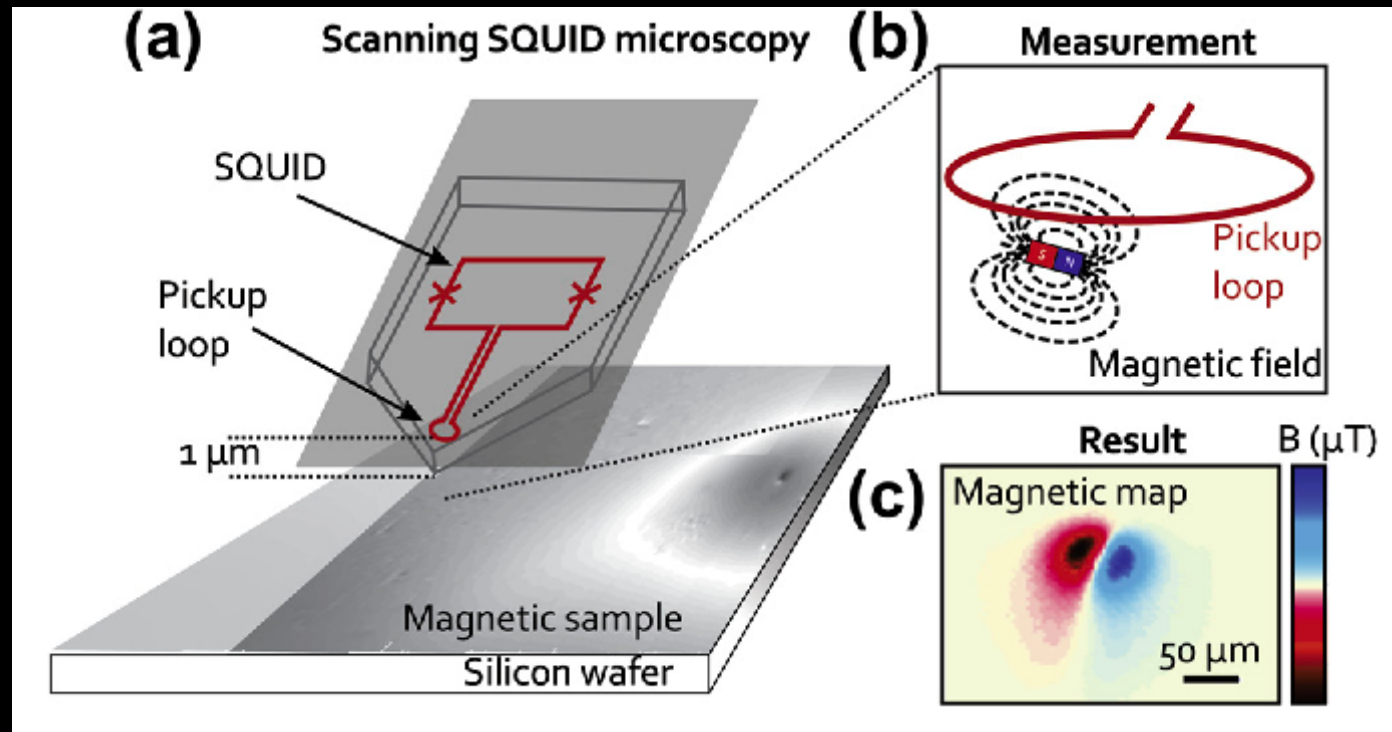


Investigation of the dynamics of Josephson vortices using a magnetic force microscope



- ✓ 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

Related Scanning Methods: SQUID

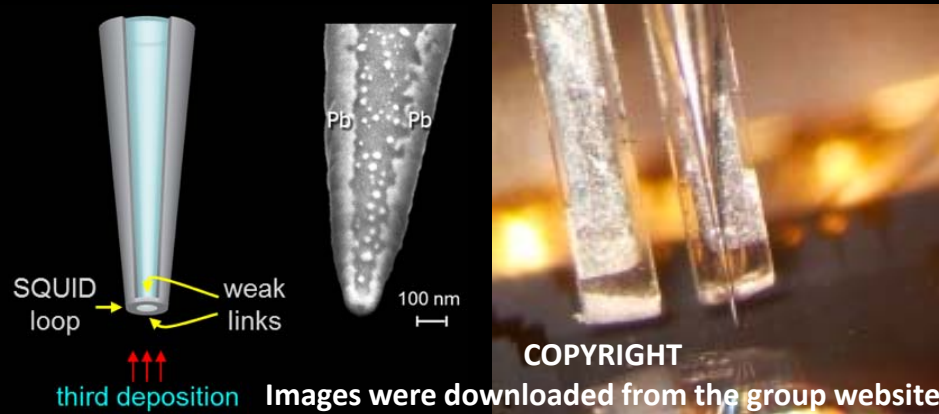


✓ S-SQUID - what is measured: the magnetic flux coming from the sample and crossing a small pickup loop of the SQUID

✓ S-Hall probe - what is measured: the component of the magnetic field perpendicular to the probe

SQUID-On-Tip Microscopy

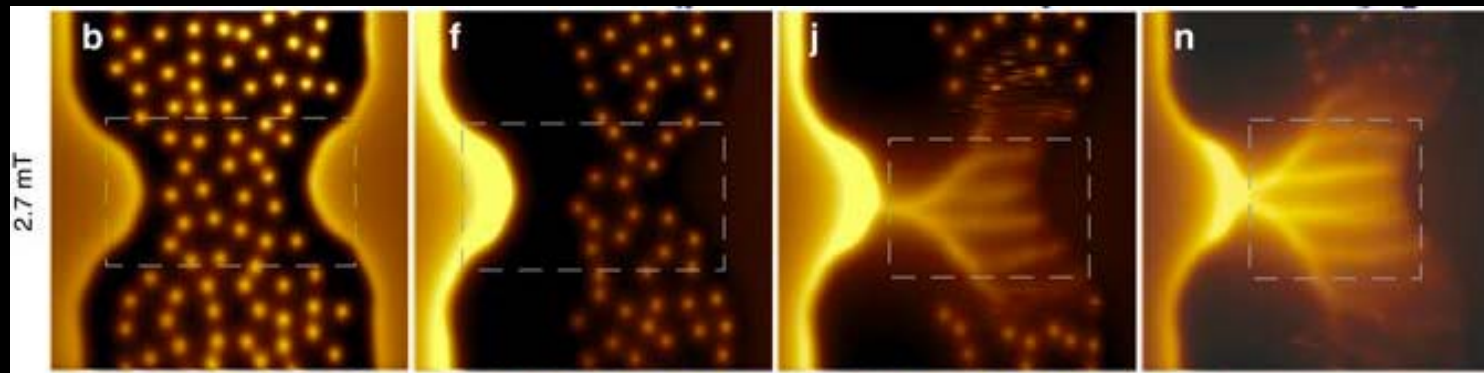
Fast magnetic imaging



Yonathan Anahory
Jerusalem
Israel



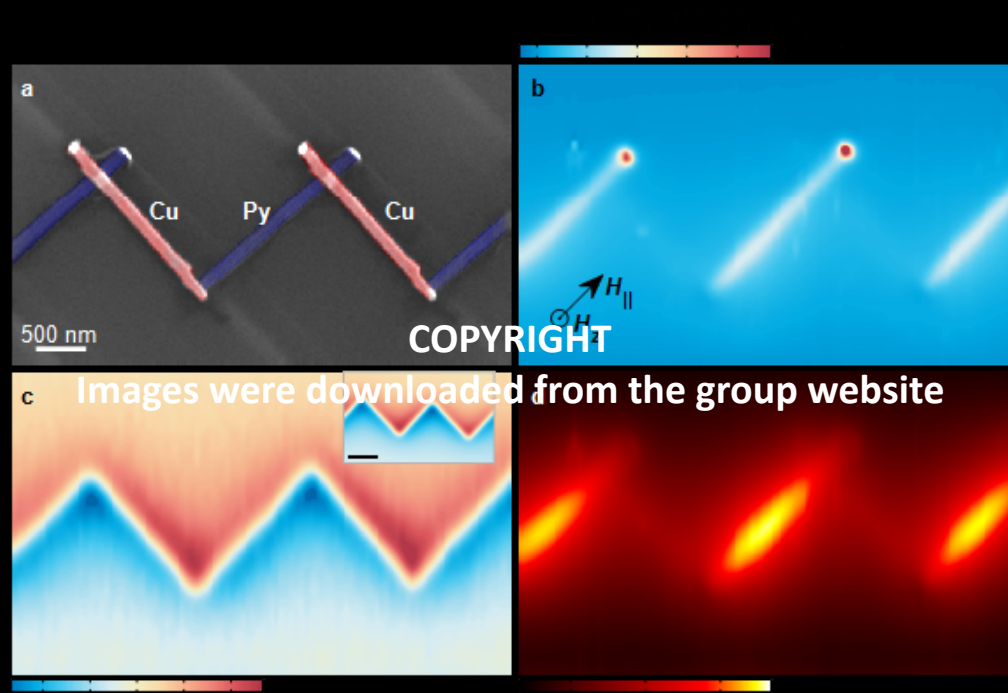
Eli Zeldov
Weizmann Institute
Israel



E. Zeldov et al. Nature Commun. 8, 85 (2017)

SQUID-On-Tip Microscopy

Thermal imaging



Images were downloaded from the group website



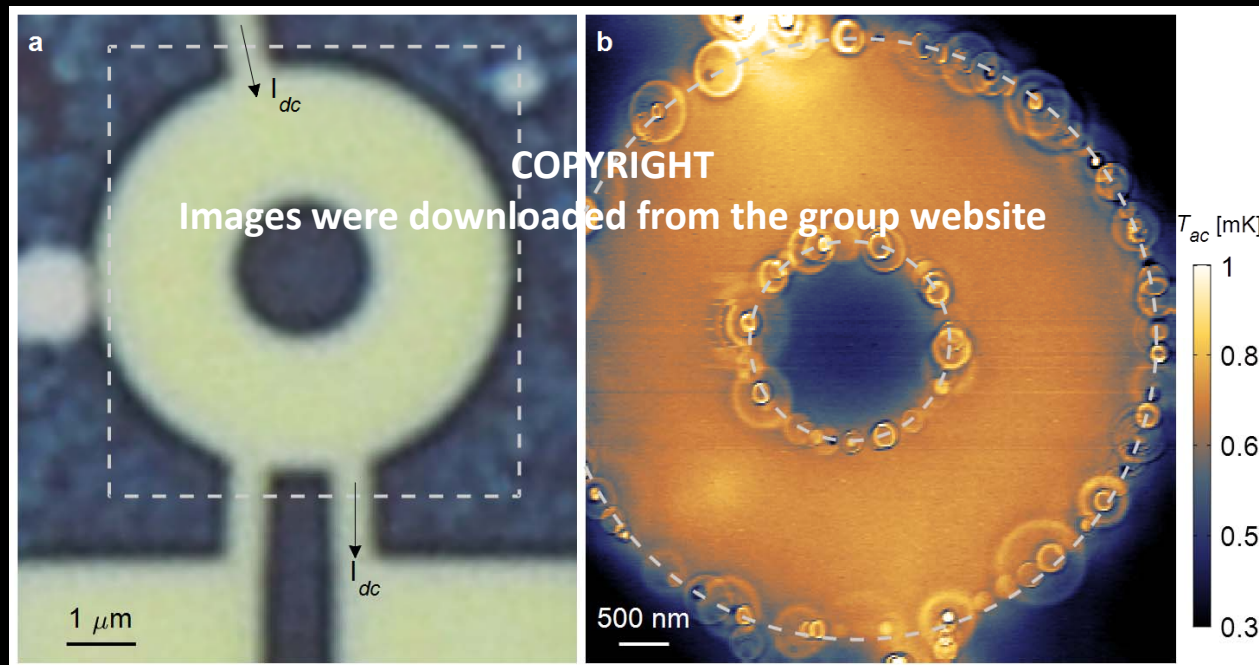
Yonathan Anahory
Jerusalem
Israel



Eli Zeldov
Weizmann Institute
Israel

SQUID-On-Tip Microscopy

Thermal imaging of individual defects



Eli Zeldov
Weizmann Institute
Israel

*E. Zeldov et al.,
Science 358, 1303-1306 (2017)*

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



NANO LETTERS

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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

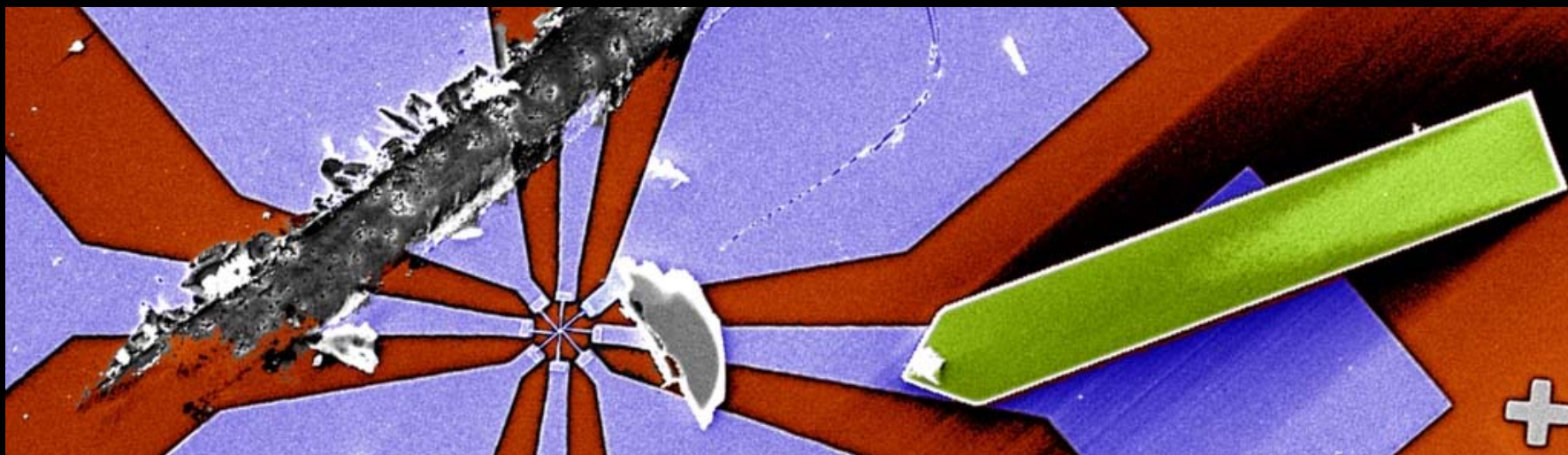
<https://doi.org/10.1038/s41467-019-11924-0>

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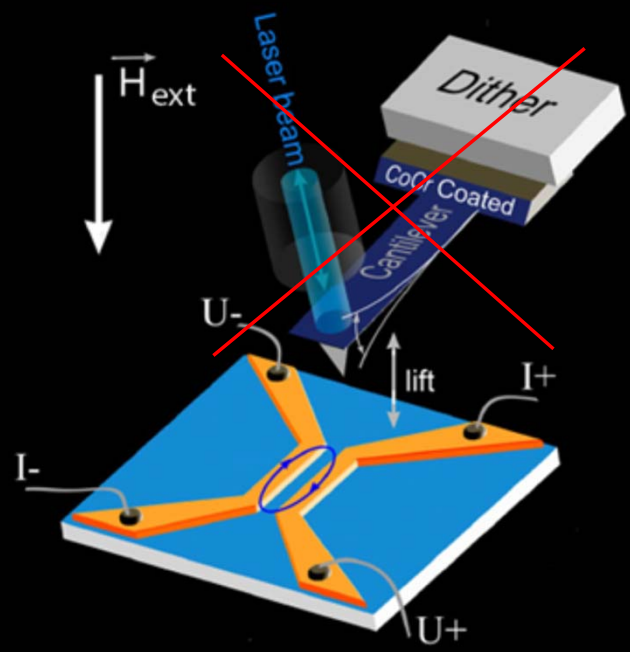
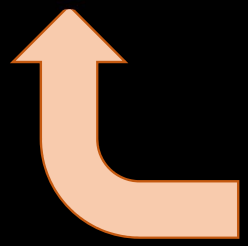
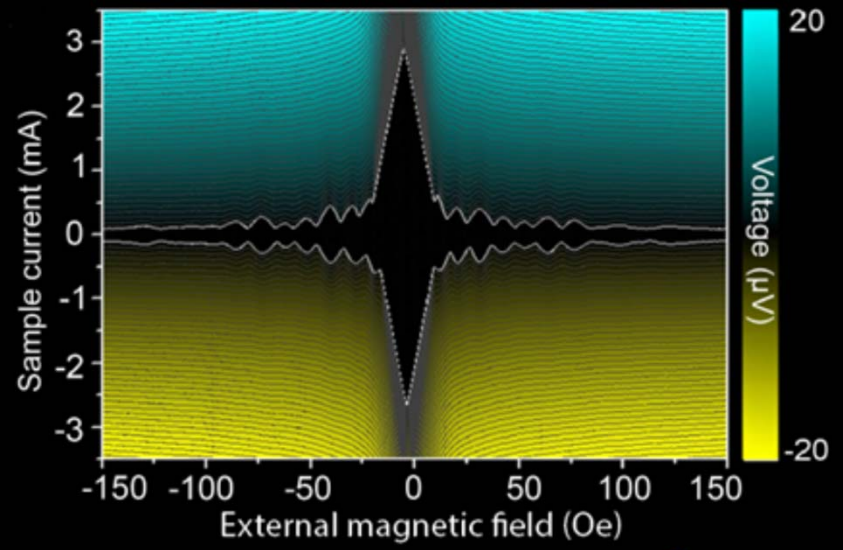
Local Josephson vortex generation and manipulation with a Magnetic Force Microscope

Viacheslav V. Dremov^{1,2}, Sergey Yu. Grebenchuk¹, Andrey G. Shishkin¹, Denis S. Baranov^{1,3,4}, Razmik A. Hovhannisyan¹, Olga V. Skryabina^{1,3}, Nickolay Lebedev¹, Igor A. Golovchanskiy^{1,5}, Vladimir I. Chichkov⁵, Christophe Brun⁶, Tristan Cren⁶, Vladimir M. Krasnov^{1,7}, Alexander A. Golubov^{1,8}, Dimitri Roditchev^{1,4,9} & Vasily S. Stolyarov^{1,5,10,11}



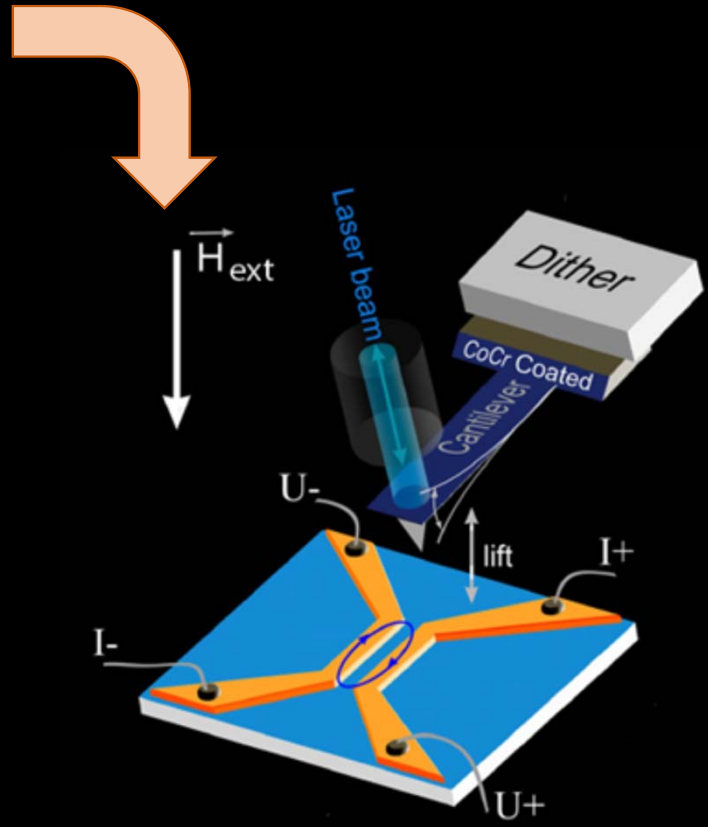
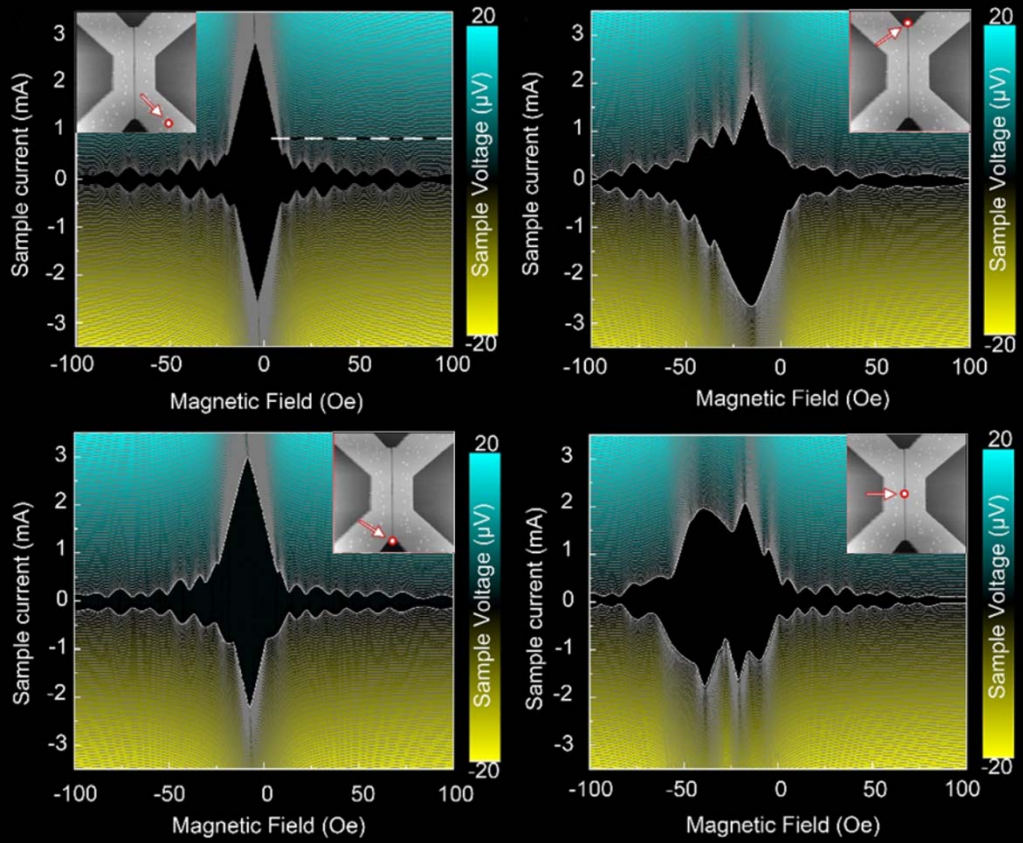


Investigation of the dynamics of Josephson vortices using a magnetic force microscope



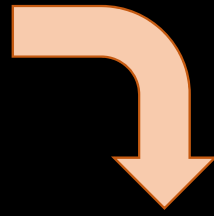
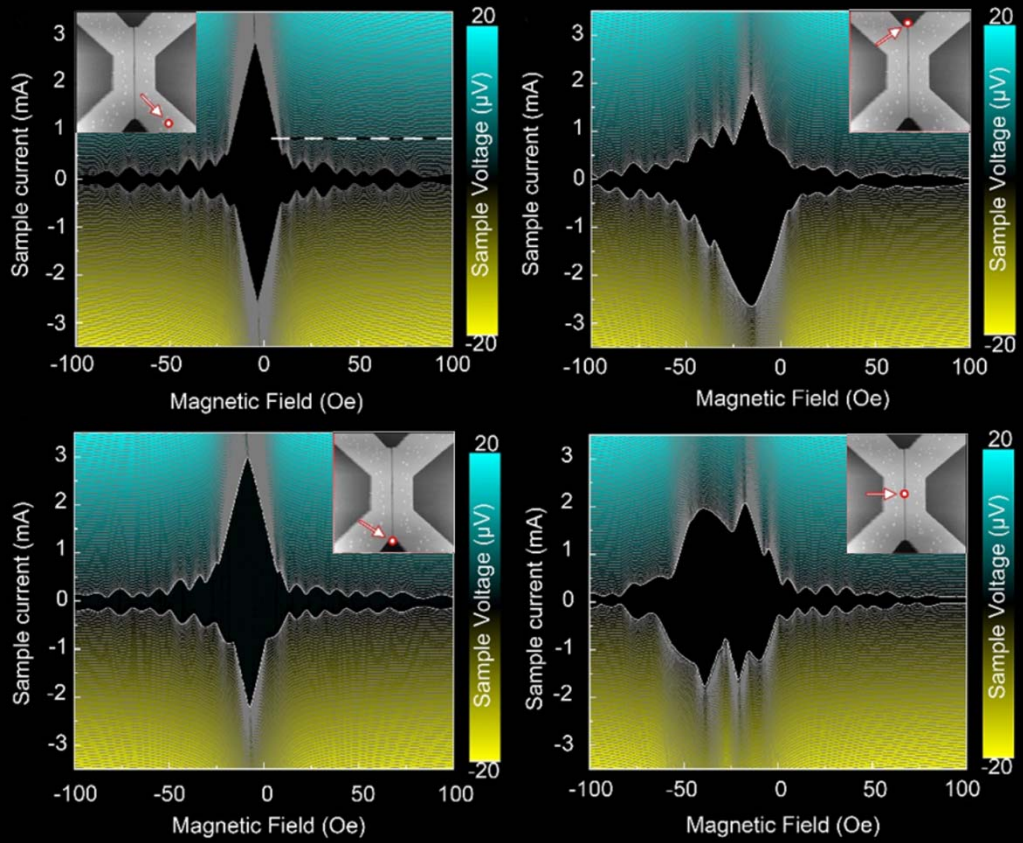


Investigation of the dynamics of Josephson vortices using a magnetic force microscope





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



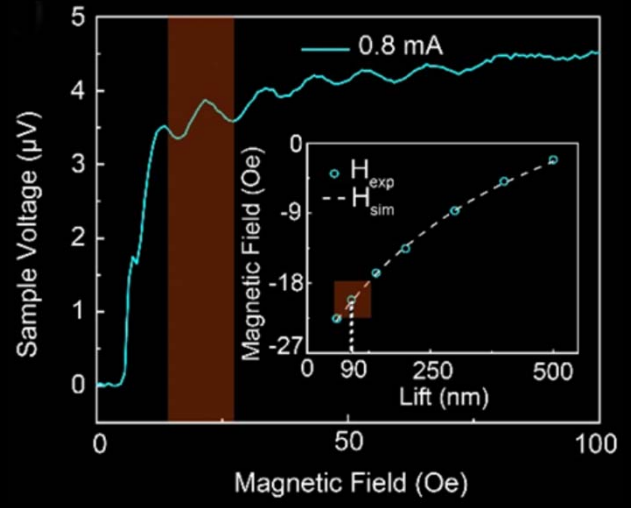
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Letter

Lateral Josephson Junctions as Sensors for Magnetic Microscopy at Nanoscale

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





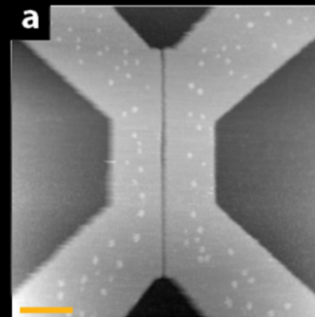
Investigation of the dynamics of Josephson vortices using a magnetic force microscope

PHYSICAL REVIEW RESEARCH 2, 023105 (2020)

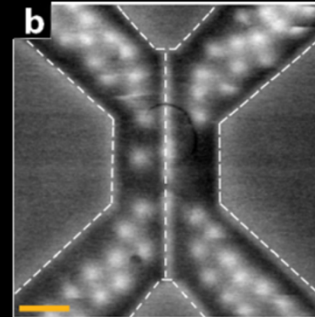
Observation of interacting Josephson vortex chains by magnetic force microscopy

Sergey Yu. Grebenchuk¹, Razmik A. Hovhannysyan¹, Viacheslav V. Dremov^{1,2}, Andrey G. Shishkin^{1,2}, Vladimir I. Chichkov³, Alexander A. Golubov^{1,4}, Dimitri Roditchev^{5,1}, Vladimir M. Krasnov^{6,1,7} and Vasily S. Stolyarov^{1,2,3,7}

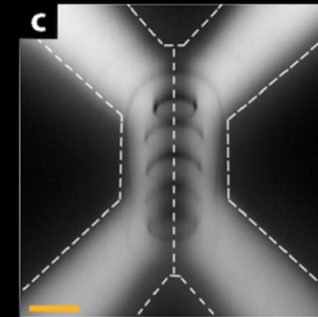
a: topographic AFM image of the device



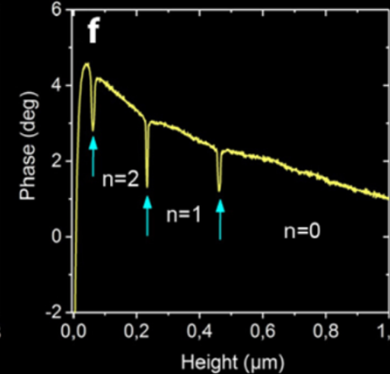
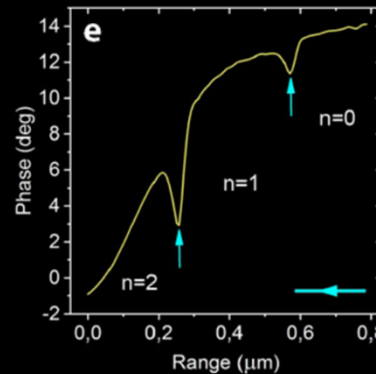
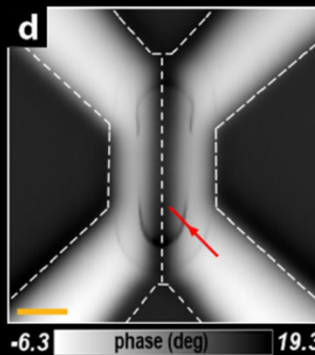
b: when the device is field cooled in a 90 Oe (the tip is raised by 150 nm).



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).



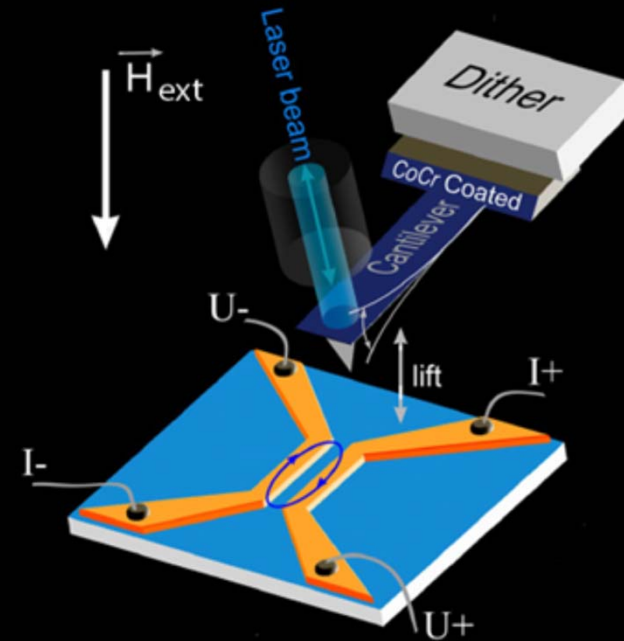
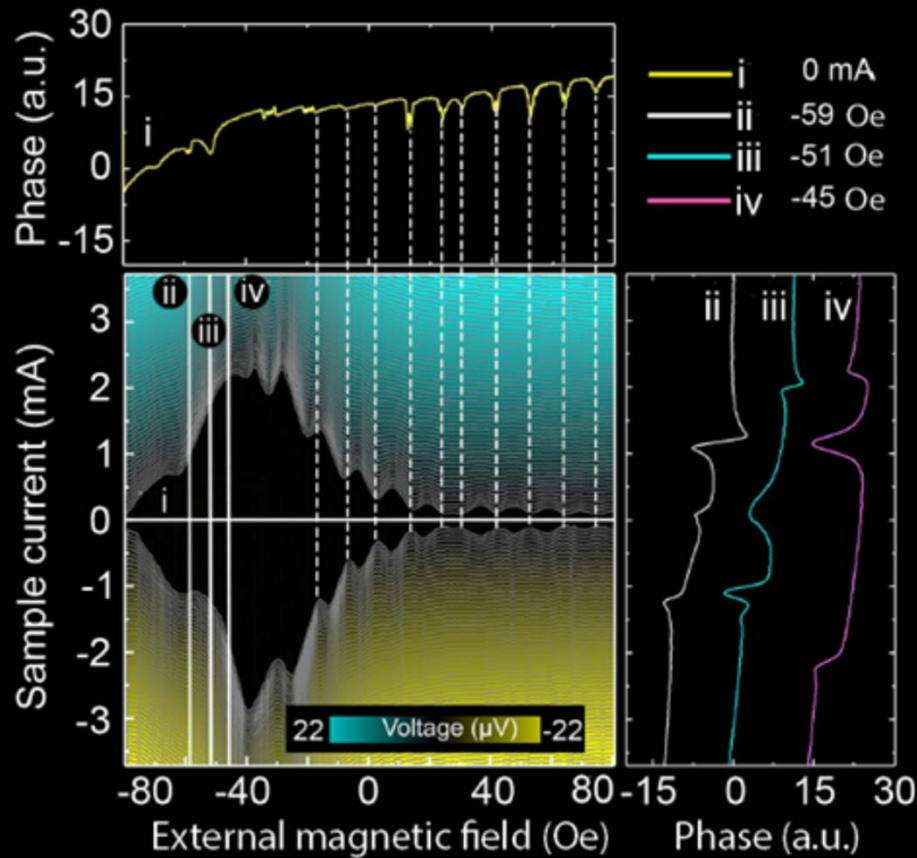
e: spatial change in the phase signal along the line indicated by the red arrow on the map.

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

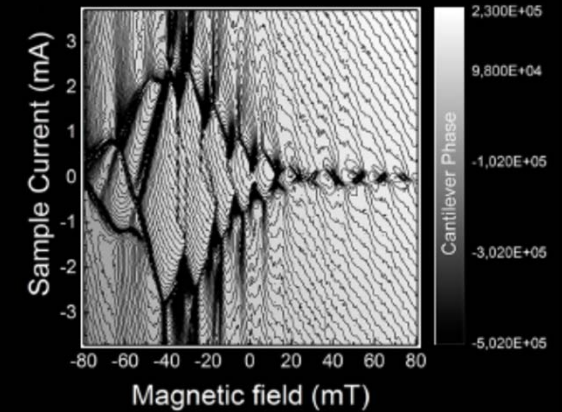
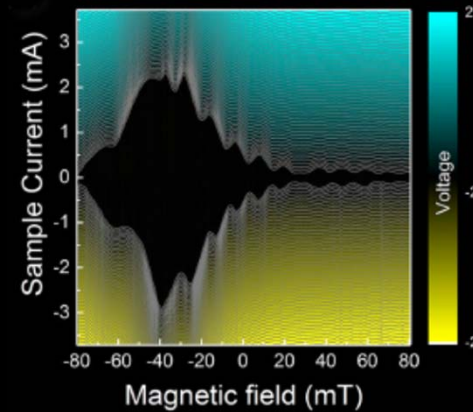
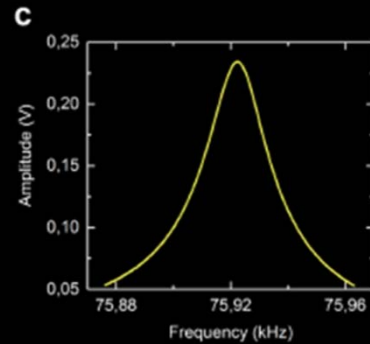
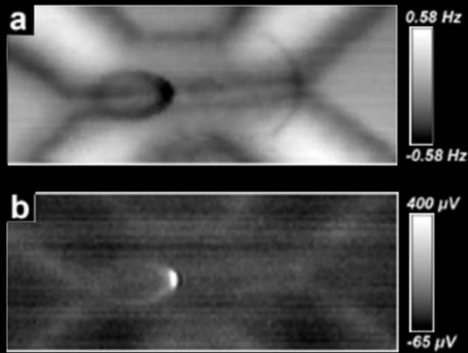


Investigation of the dynamics of Josephson vortices using a magnetic force microscope





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.

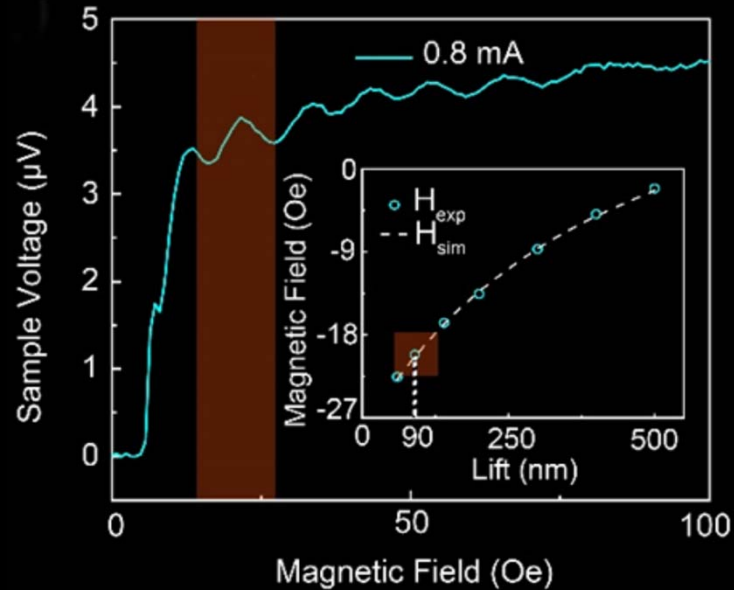
$$A_{exc} = z_0/Q \rightarrow \delta A_{exc} \rightarrow \delta Q = -Q \delta A_{exc}/A_{exc} \qquad \delta P_{dis} \sim 2.2 \cdot 10^{-15} \text{ W.}$$

$$P_{dis} = \frac{kz_0^2 \omega_0}{2Q} \rightarrow \delta P_{dis} \rightarrow \delta P_{dis} = -\delta Q \frac{kz_0^2 \omega_0}{2Q^2} = -P_{dis} \delta Q/Q = P_{dis} \delta A_{exc}/A_{exc}$$

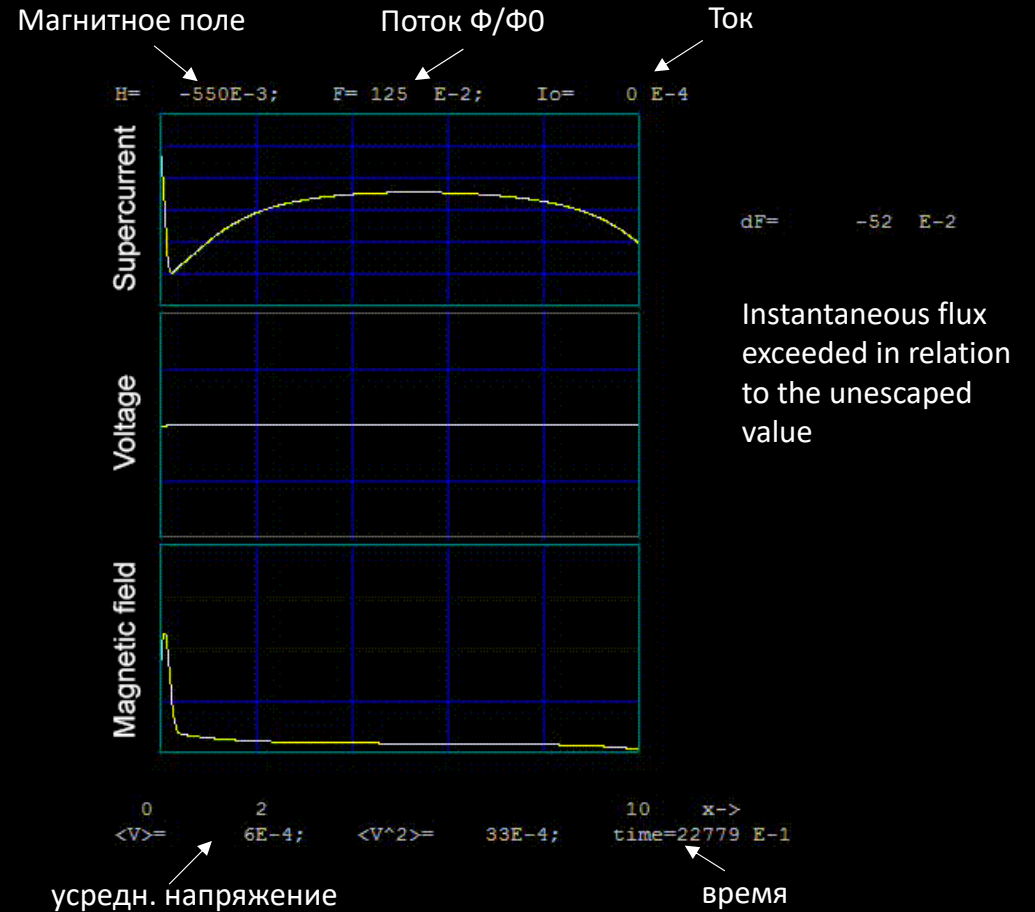
$$P_{dis} \sim 8.8 \cdot 10^{-14} \text{ W}$$



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

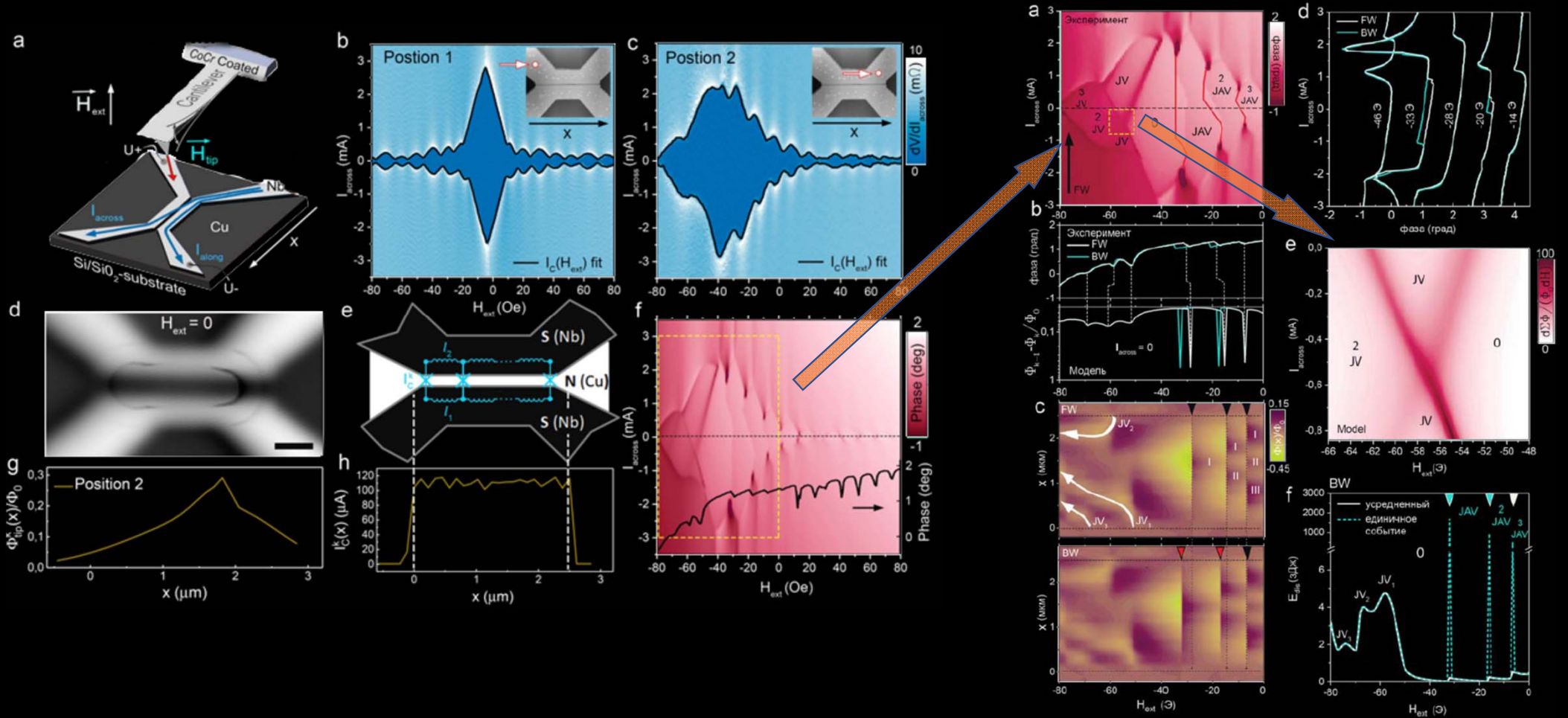


What happens in one period of oscillation of a cantilever?





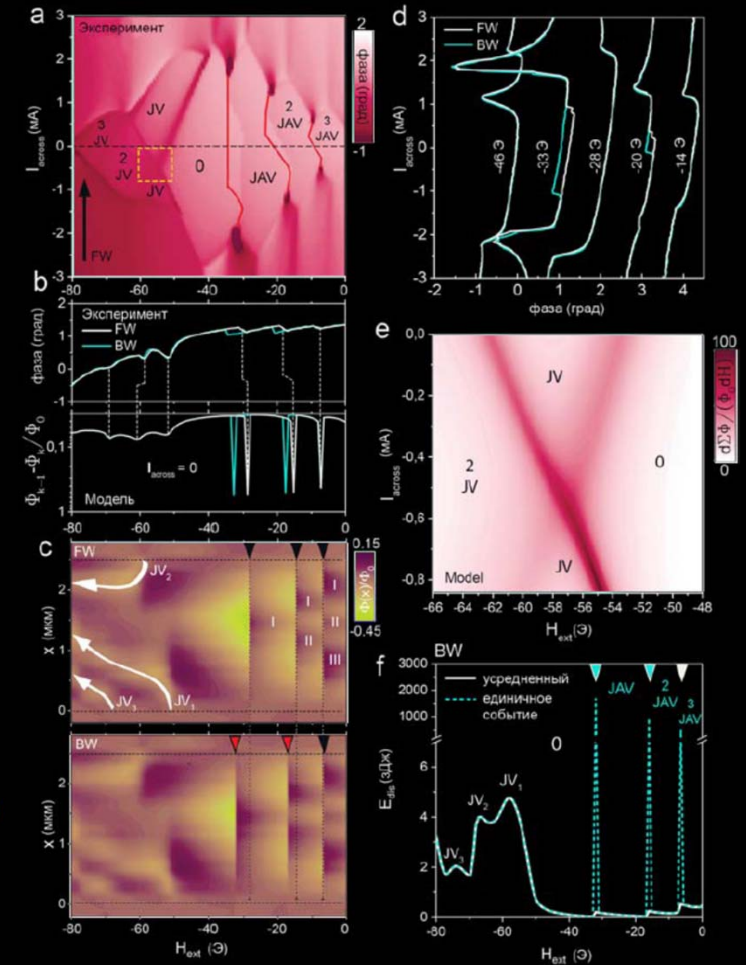
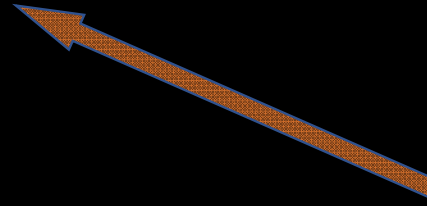
Investigation of the dynamics of Josephson vortices using a magnetic force microscope





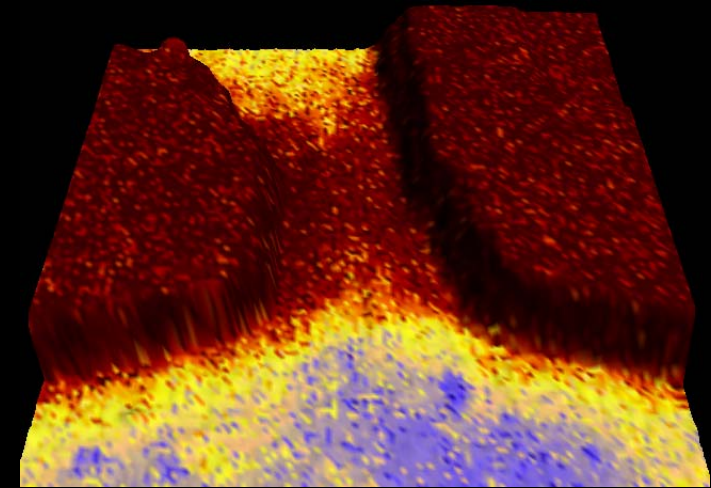
Investigation of the dynamics of Josephson vortices using a magnetic force microscope

$JV \rightarrow JV$	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



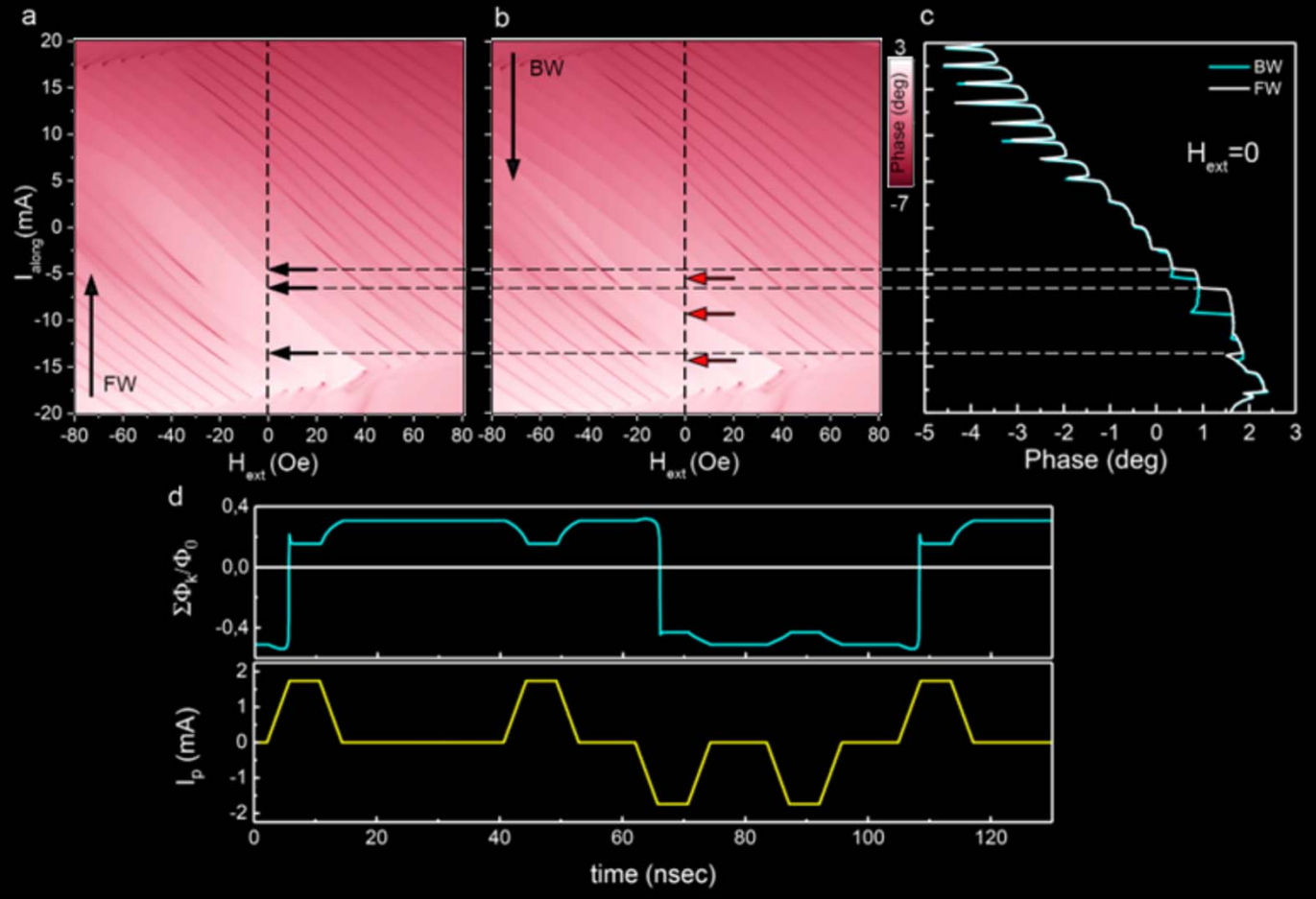
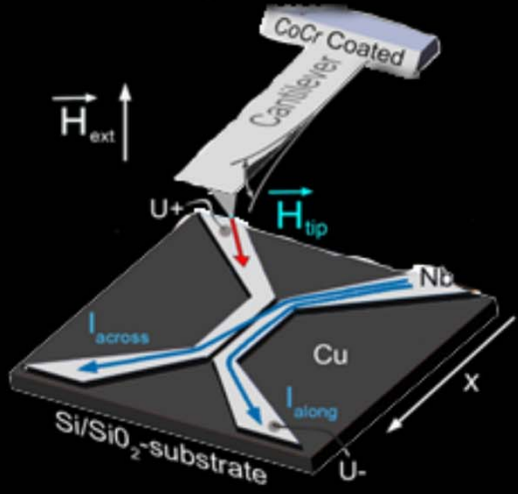
Josephson vortex as a logical state of low-dissipative devices

Part 3: Logical state by SNS



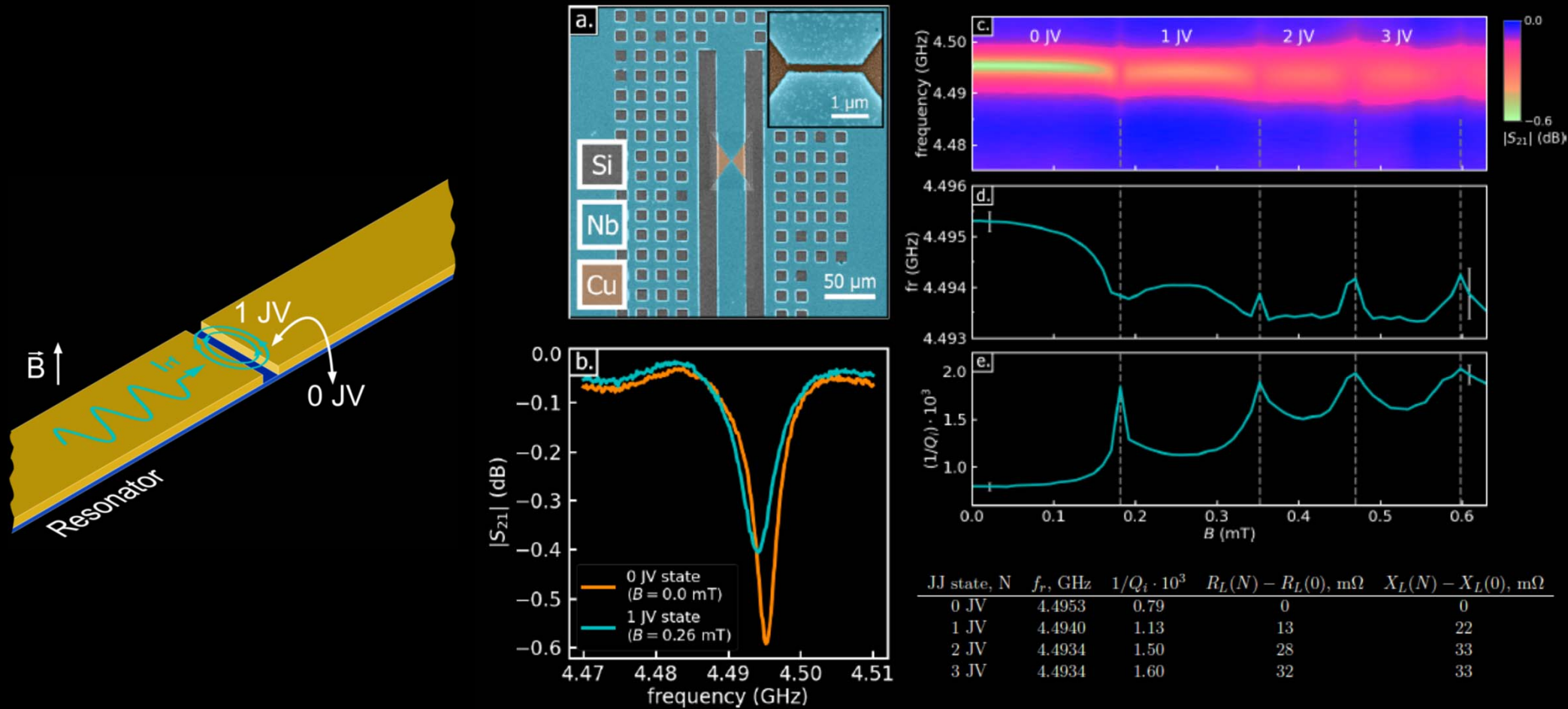


Implementation of a logical device on a chip



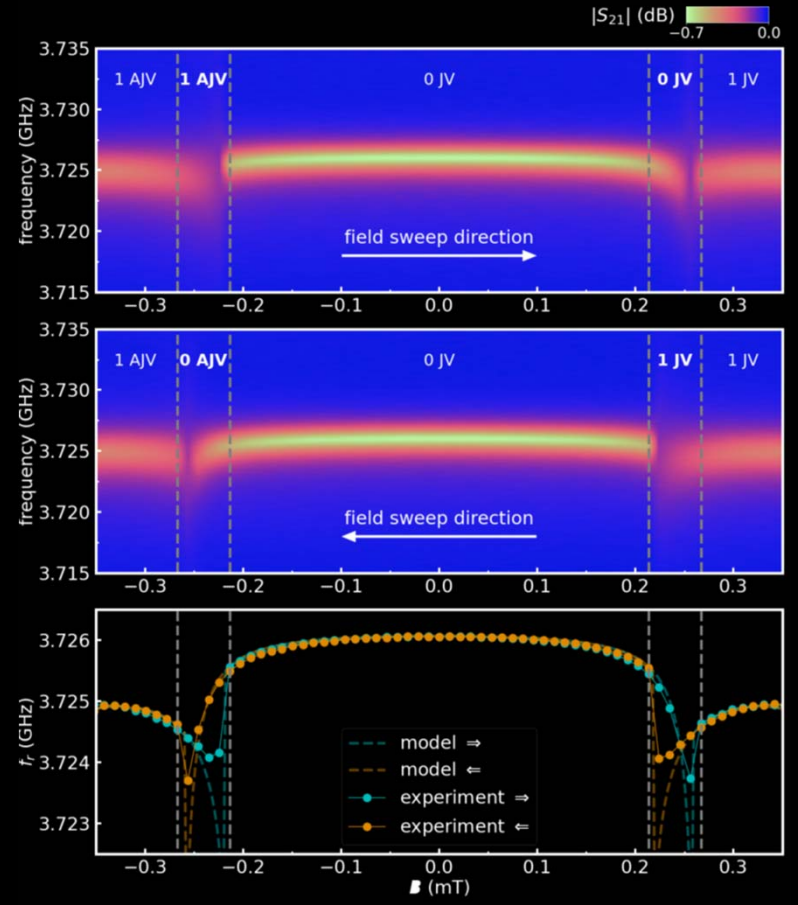
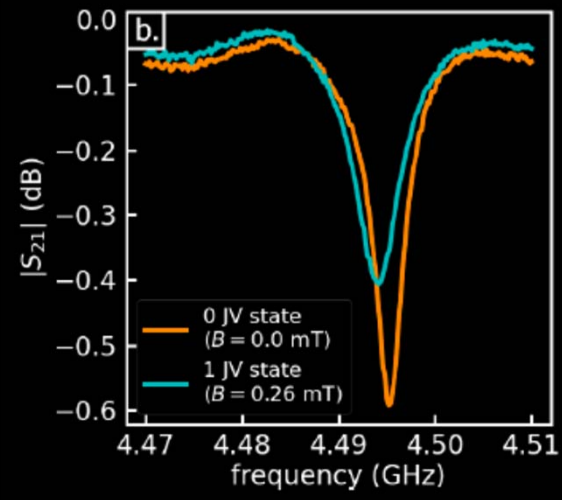
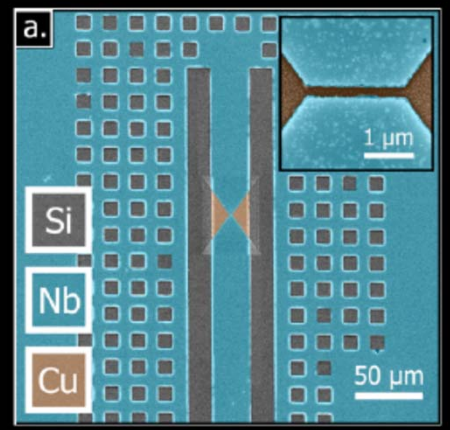
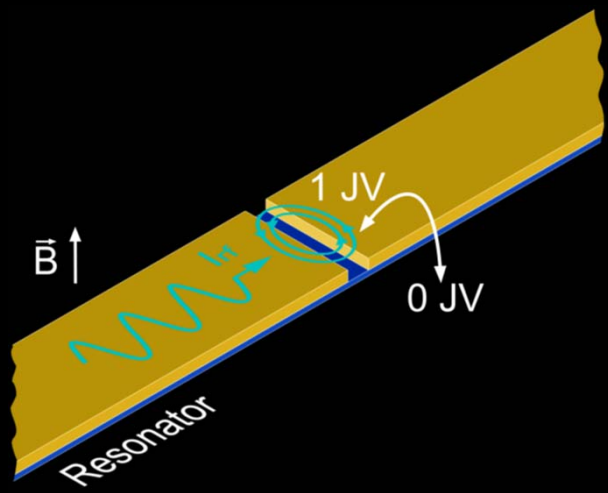


Implementation of a logical device on a chip



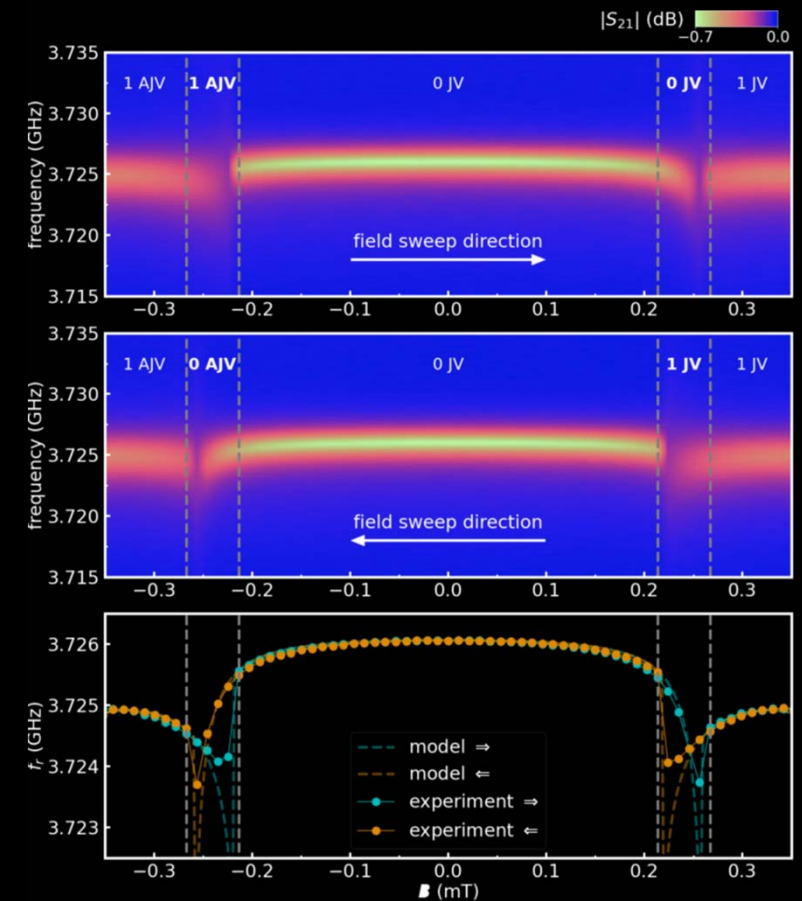
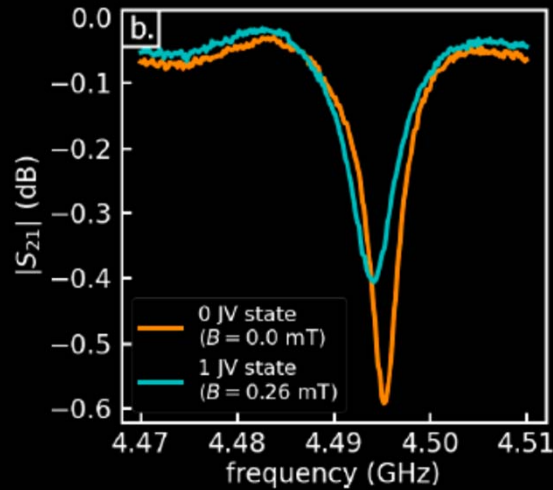
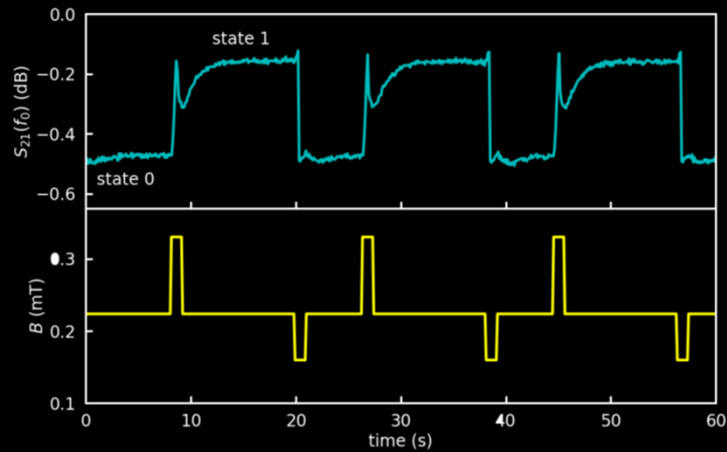
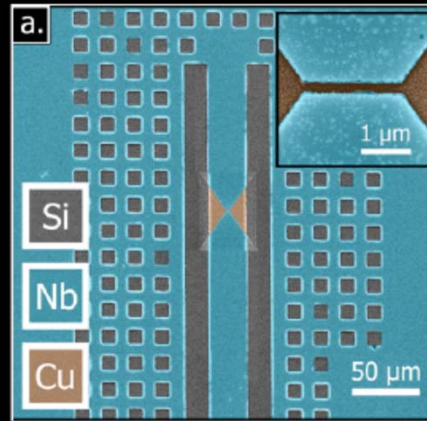
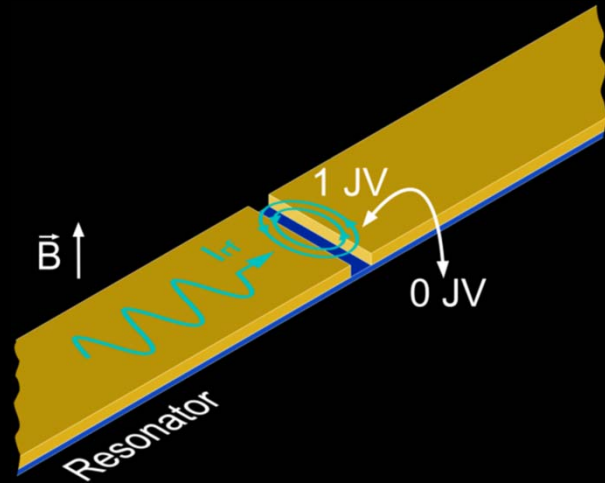


Implementation of a logical device on a chip



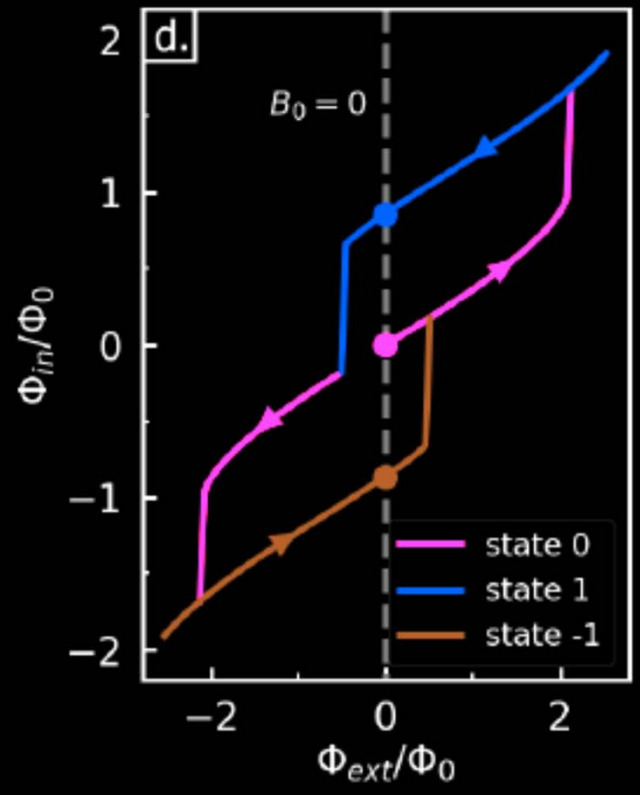
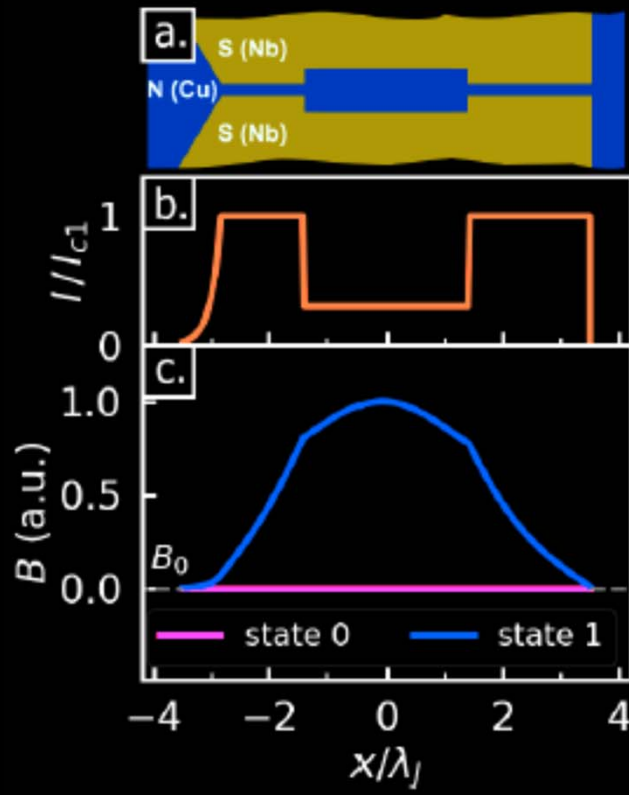
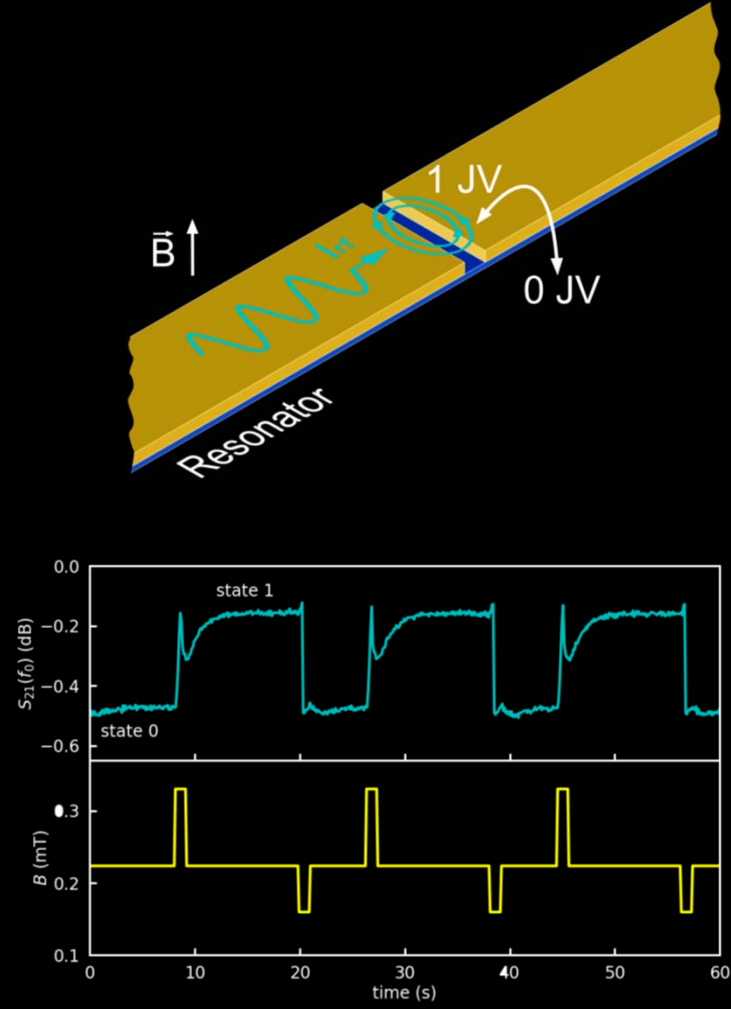


Implementation of a logical device on a chip





Implementation of a logical device on a chip



Submitted to the Nature Electronics