Josephson coupling in unconventional & extreme conditions

Francesco Tafuri

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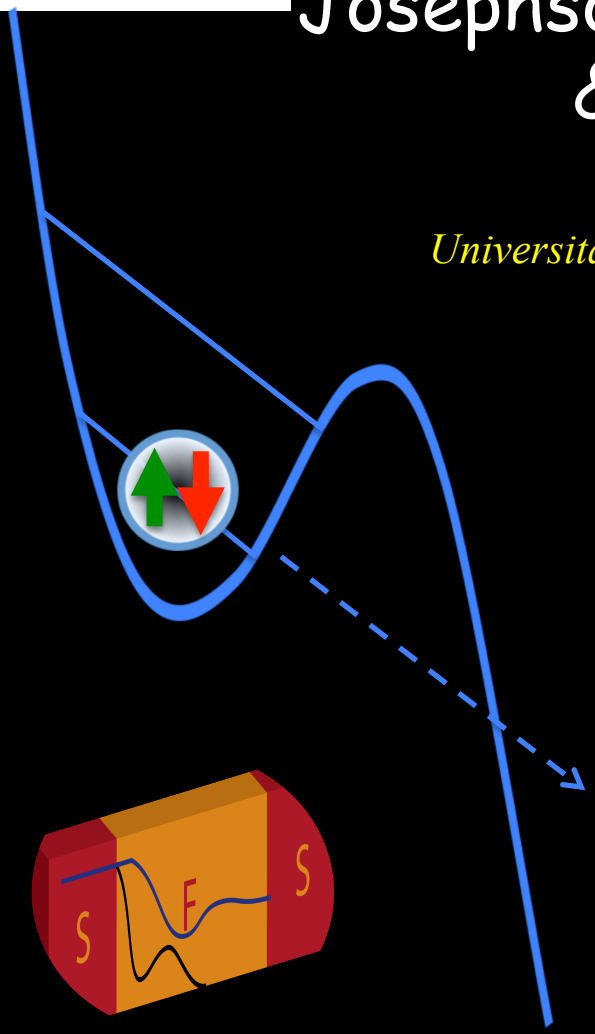
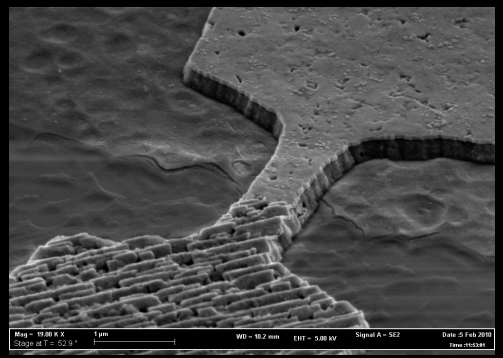
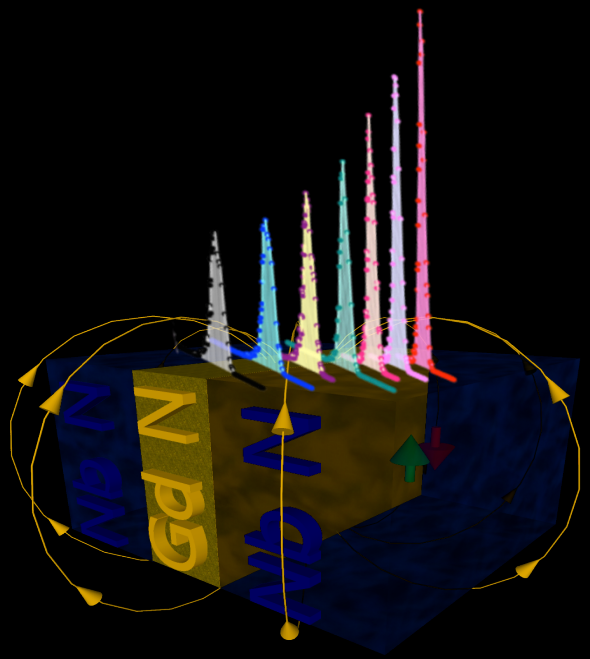






Floriana Lombardi, Thilo Bauch,
Luca Galletti, Domenico Montemurro

Chalmers University, Sweden

Mark Blamire, Avdradeep Pal, Niladri

Cambridge University, UK

Oleg Mukanhov and Igor Vernik

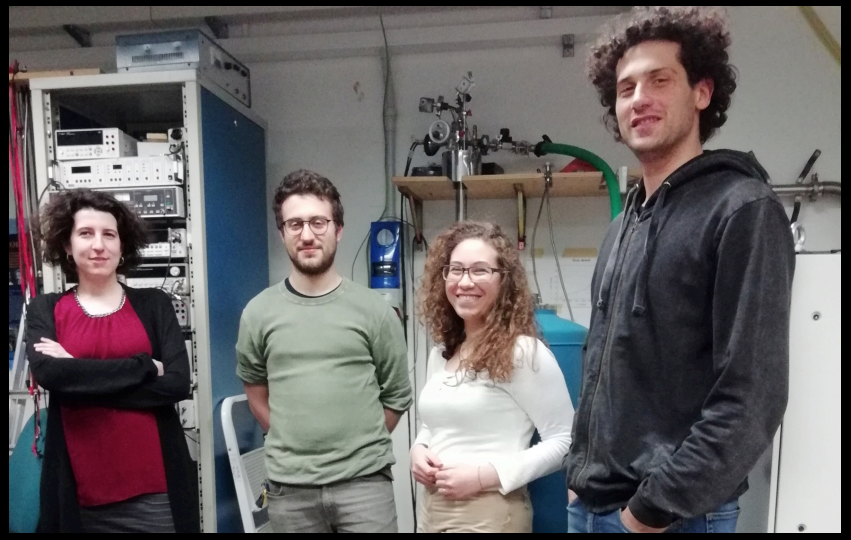
Hypres Inc., NY, USA

Valery Ryazanov

Moscow University, Russia

John Kirtley

IBM / Stanford University, CA, USA



Davide Massarotti, Daniela Stornaiuolo,
Roberta Caruso, Halima Ahmad,
Alessandro Miano & Giampiero Pepe

Procolo Lucignano, Gabriele Campagnano,
Giacomo Rotoli, Arturo Tagliacozzo

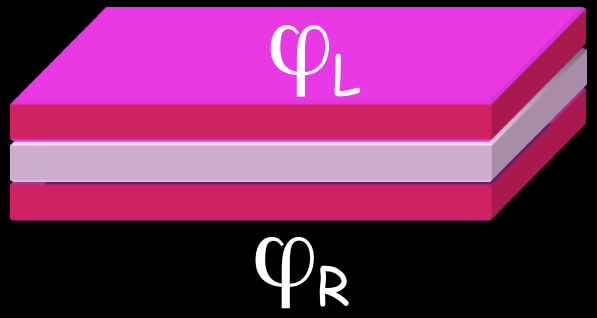
The Josephson effect

$$\begin{cases} I_S(\varphi) = I_C \sin\varphi \\ \dfrac{\partial\varphi}{\partial t} = \dfrac{2eV}{\hbar} \end{cases}$$

$$\varphi = \varphi_L - \varphi_R$$

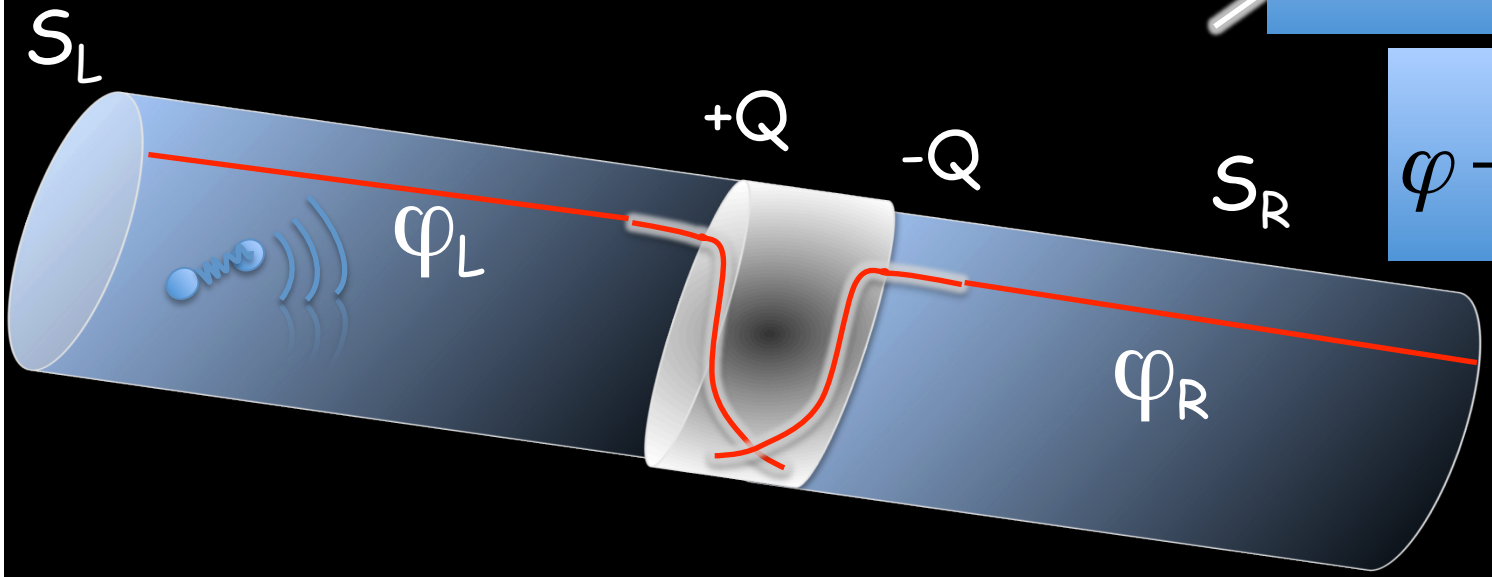
$$H = E_C (Q/e)^2 - E_J \cos\varphi$$

$$\left[\varphi, Q\right] = i2e \qquad E_J << E_C$$



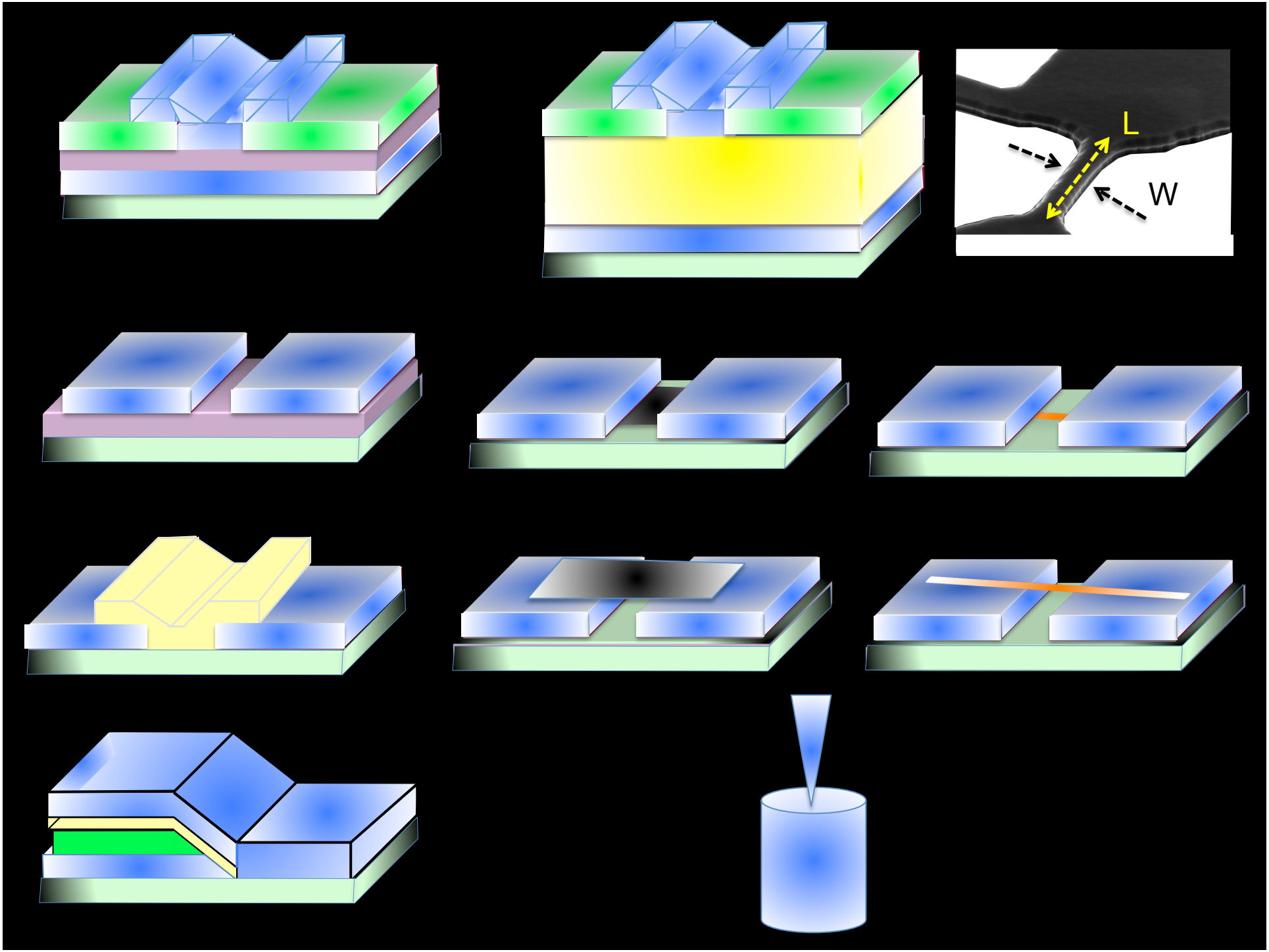
$$2eN = Q = CV$$

$$N \rightarrow E_C = \frac{e^2}{2C}$$

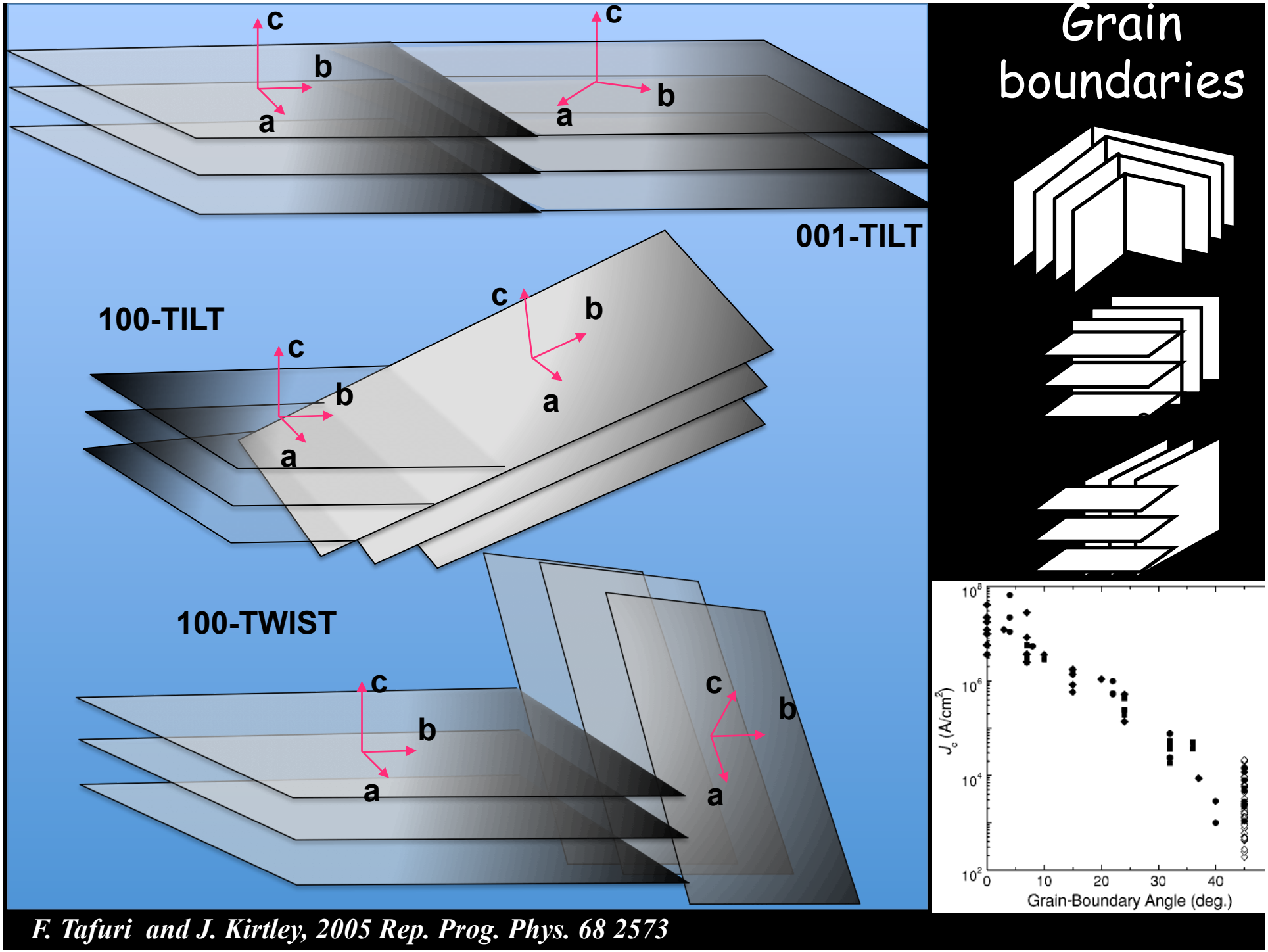


$$\varphi \rightarrow E_J = \frac{I_c \phi_o}{2\pi}$$

$$E_J >> E_C$$

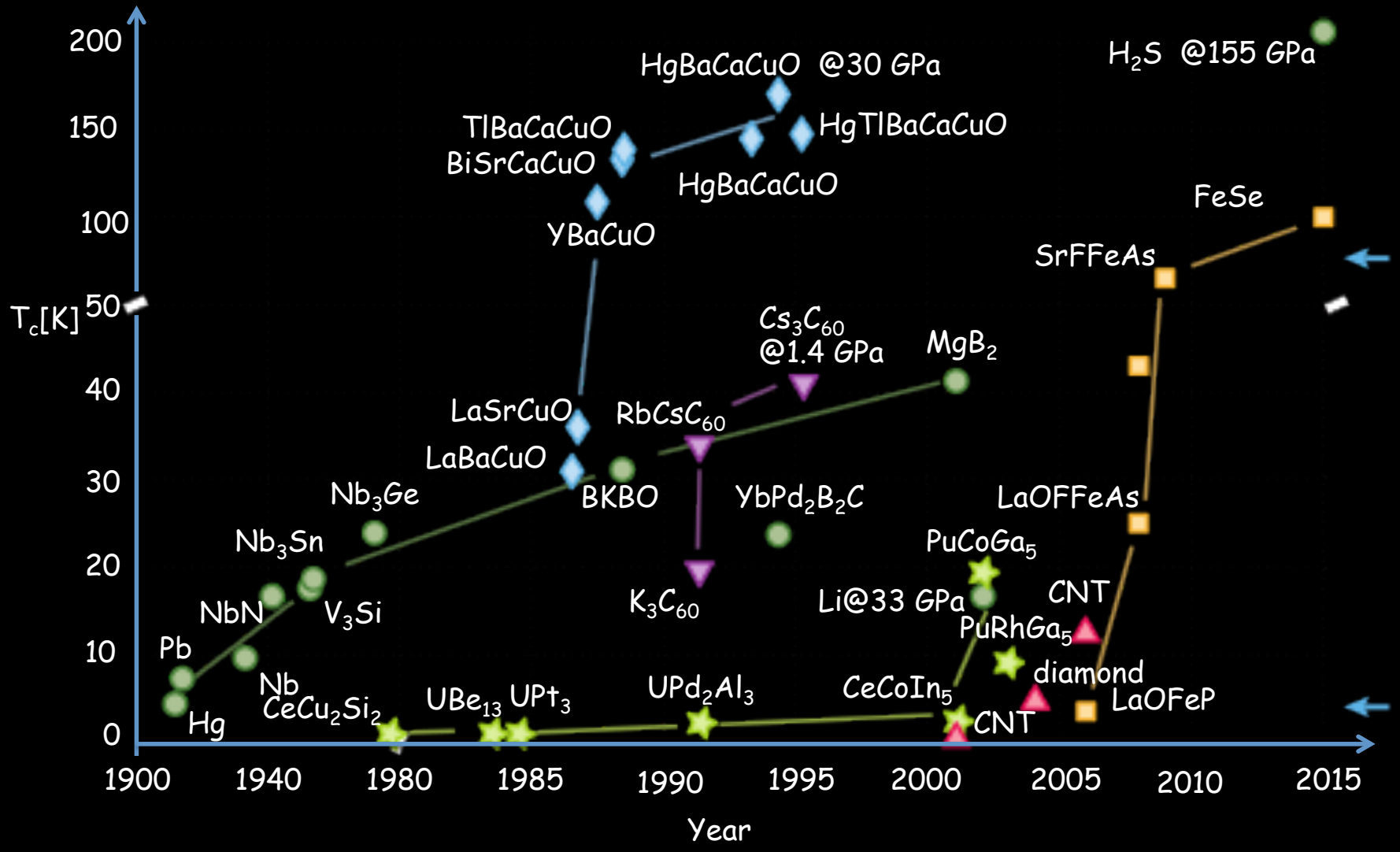

L
W

Grain boundaries

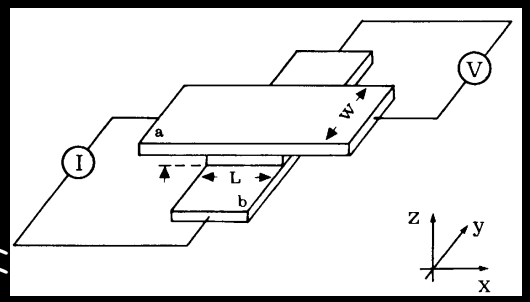


F. Tafuri and J. Kirtley, 2005 Rep. Prog. Phys. 68 2573

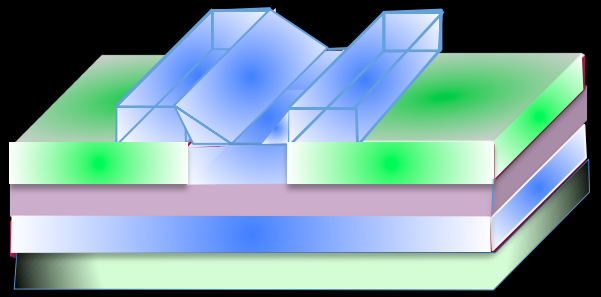
Material Science driving Superconductivity



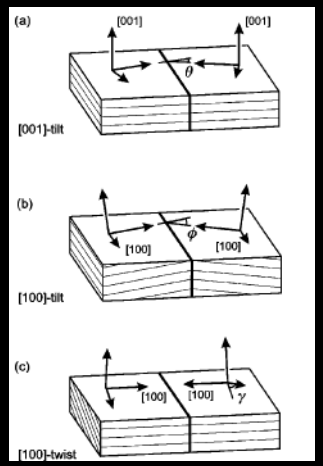
Material Science approaches & Josephson junctions

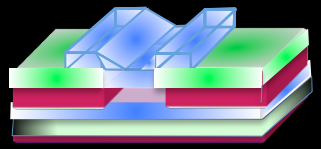


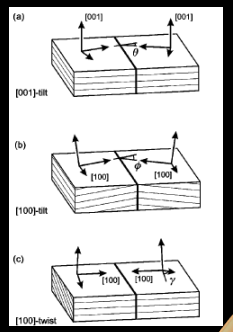
The notion of an artificial barrier

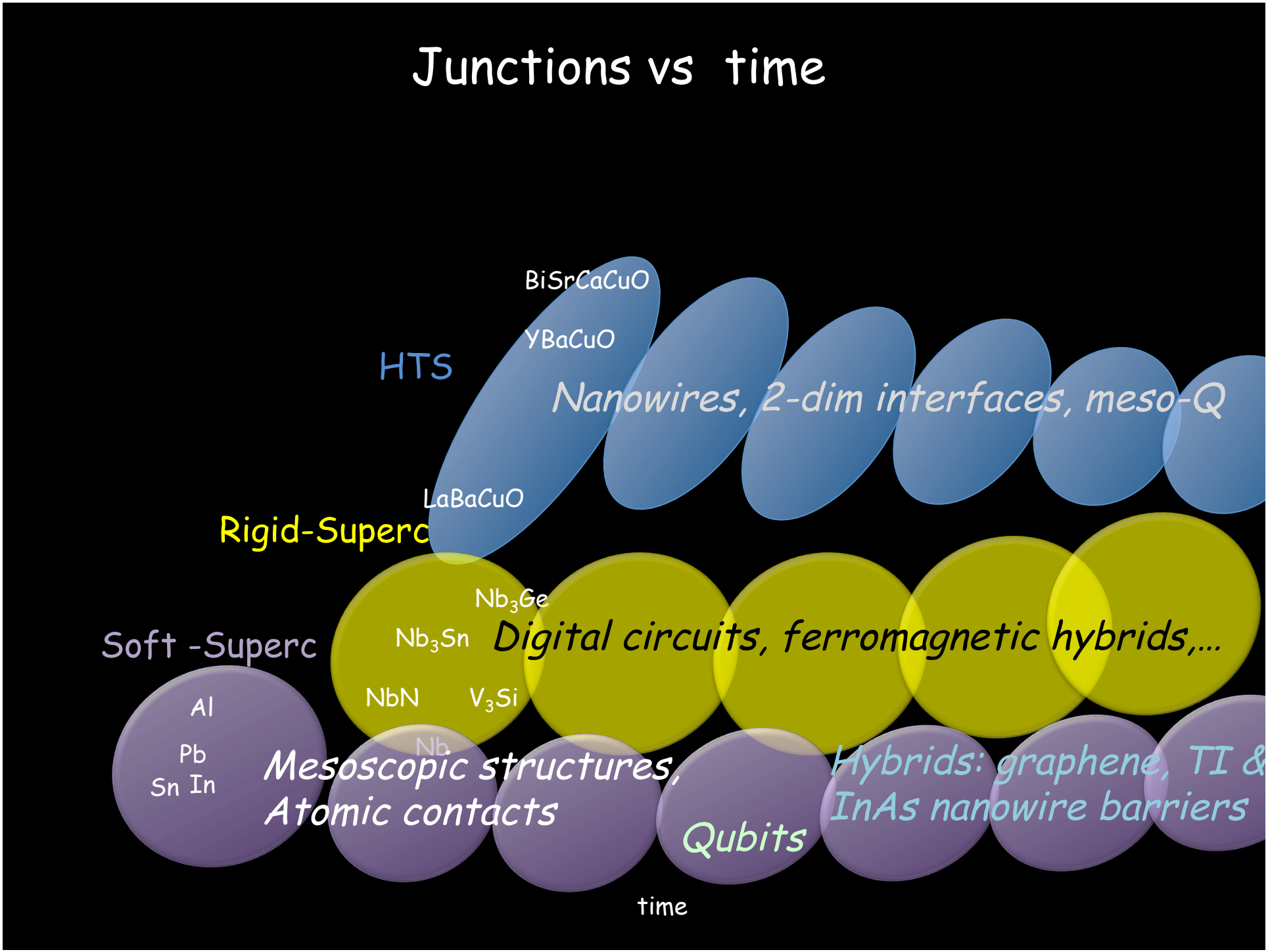


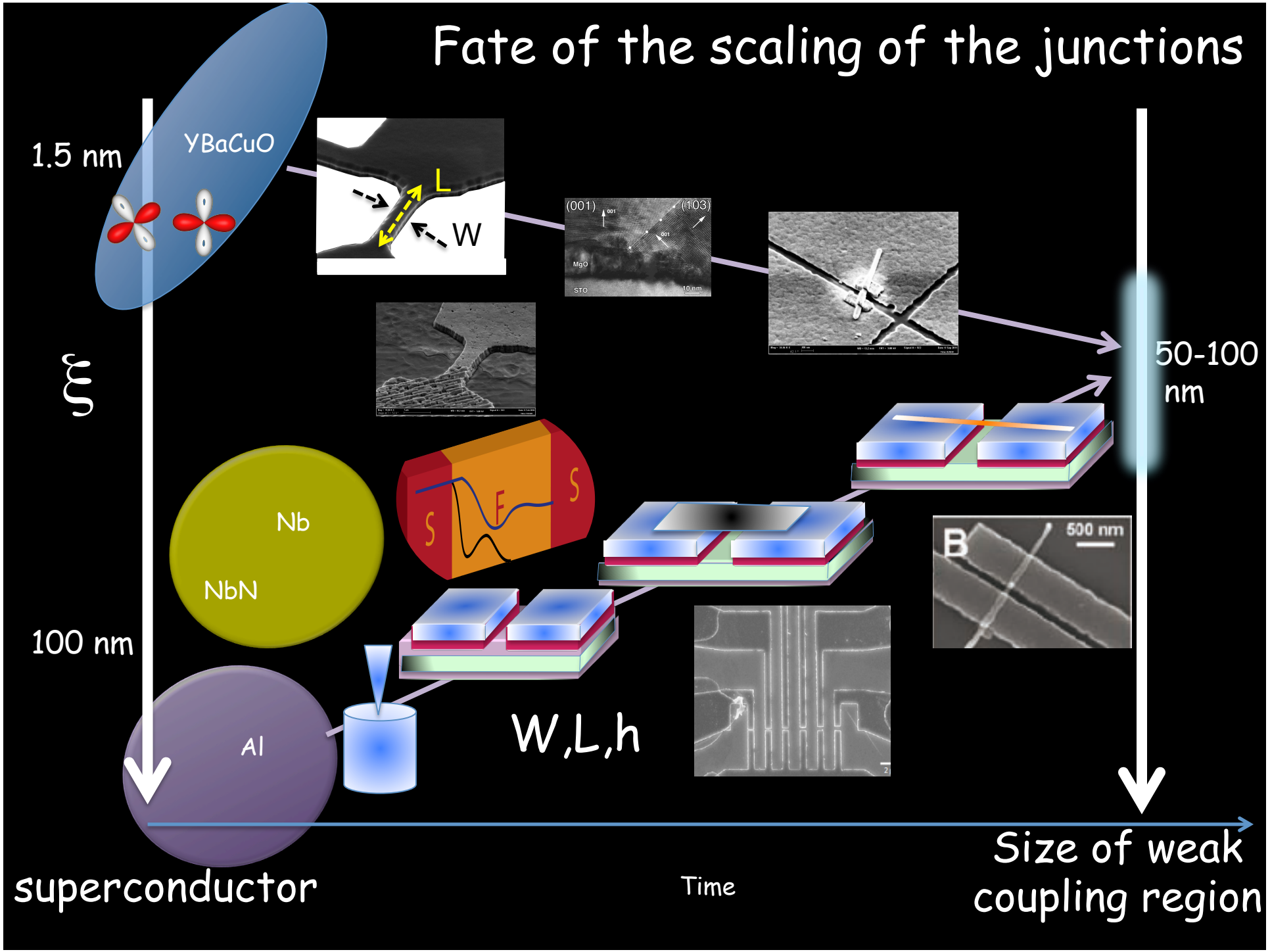
Material Science approaches & Josephson junctions





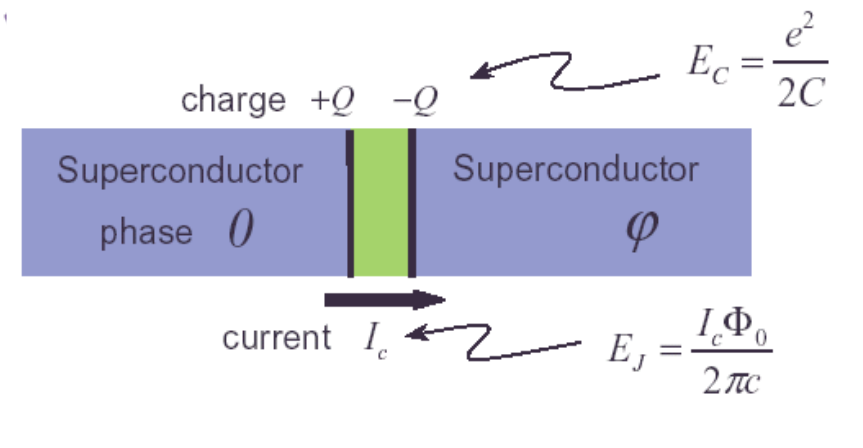


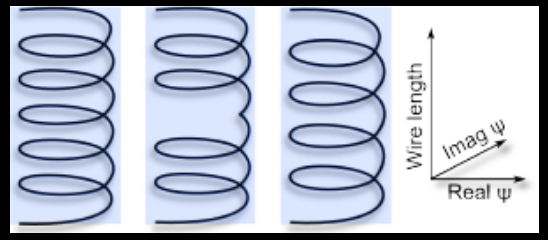

Junctions vs time
BiSrCaCuO
YBaCuO
HTS
Nanowires, 2-dim interfaces, meso-Q
LaBaCuO
Rigid-Superc
Nb3Ge
Soft -Superc
Nb3Sn
Digital circuits, ferromagnetic hybrids,…
NbN
V3Si
Nb
Al
Pb
Sn In
Mesoscopic structures,
Atomic contacts
Qubits
Hybrids: graphene, TI &
InAs nanowire barriers
time

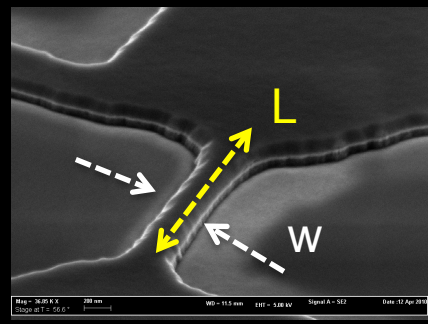

Fate of the scaling of the junctions
1.5 nm
YBaCuO
ξ
100 nm
L
W
(001)
(103)
MgO
STO
10 nm
50-100 nm
Nb
NbN
Al
S
F
S
B
500 nm
W,L,h
superconductor
Time
Size of weak coupling region

The perception that is important what …. is not on the first page of a textbook on the JE

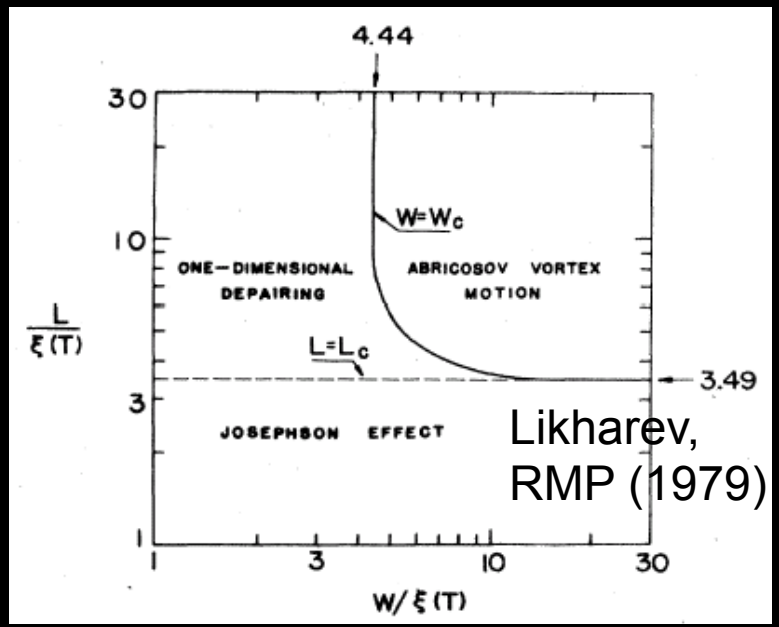
- π-junctions (d-wave, ferromag. barriers,…)
- particle-phase duality (relation between Coulomb and Josephson energies)







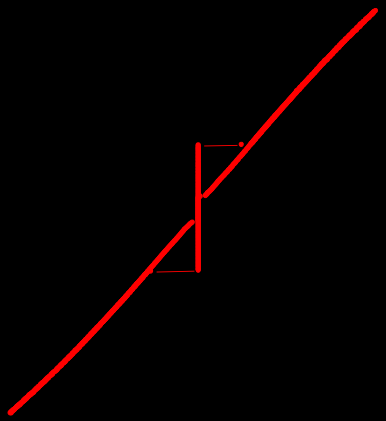
- higher order harmonics in the current-phase relation (barrier transparency,…) and the notion of non-equilibrium
- and the hidden contiguity of the different families of weak links

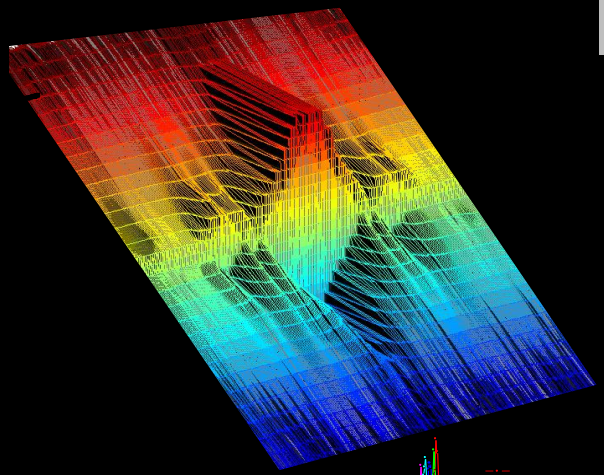


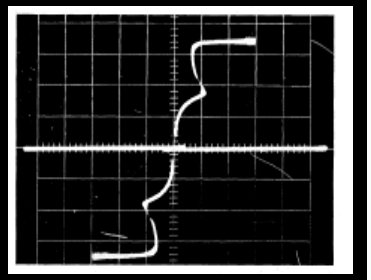
Likharev, RMP (1979)

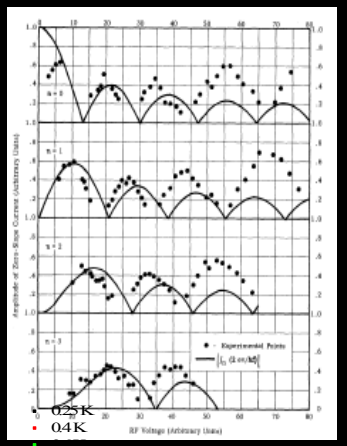
- Coupling with the environment
- Current distribution
- Barrier stability
- Topology of the contact

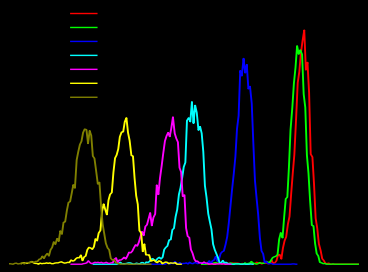
Codes and languages of the Josephson effect

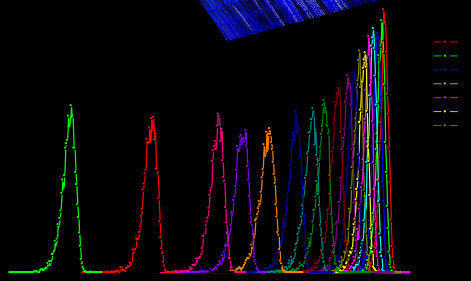


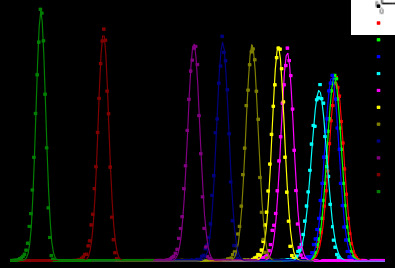






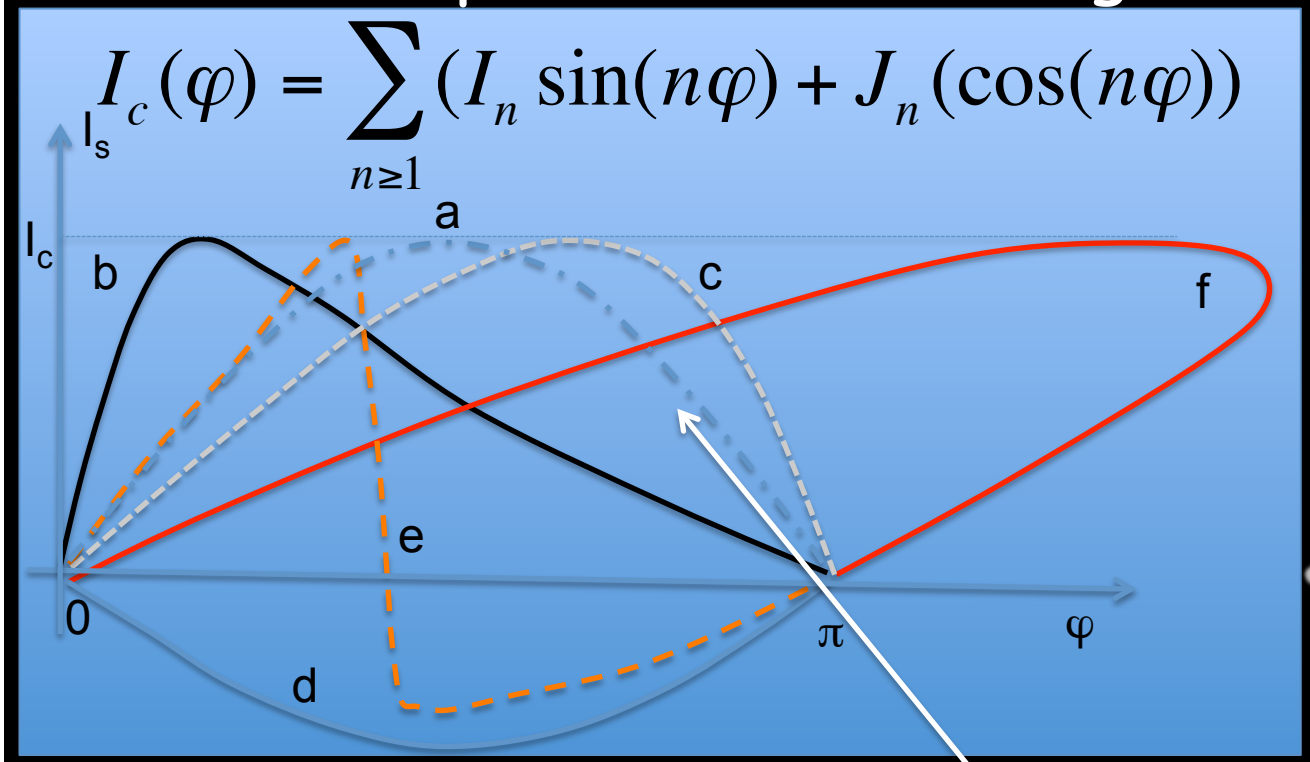


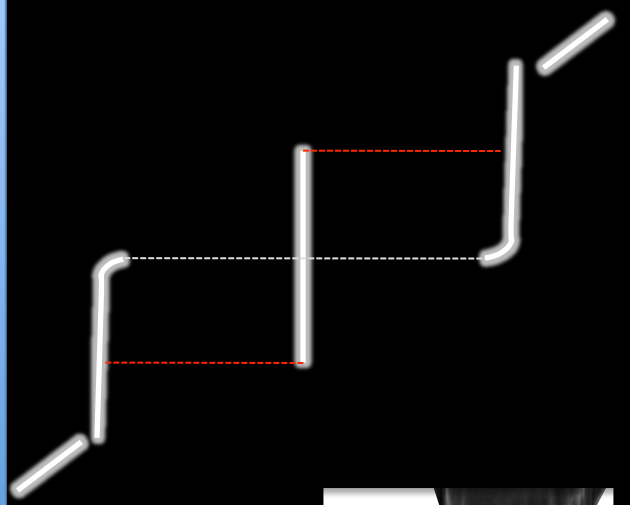


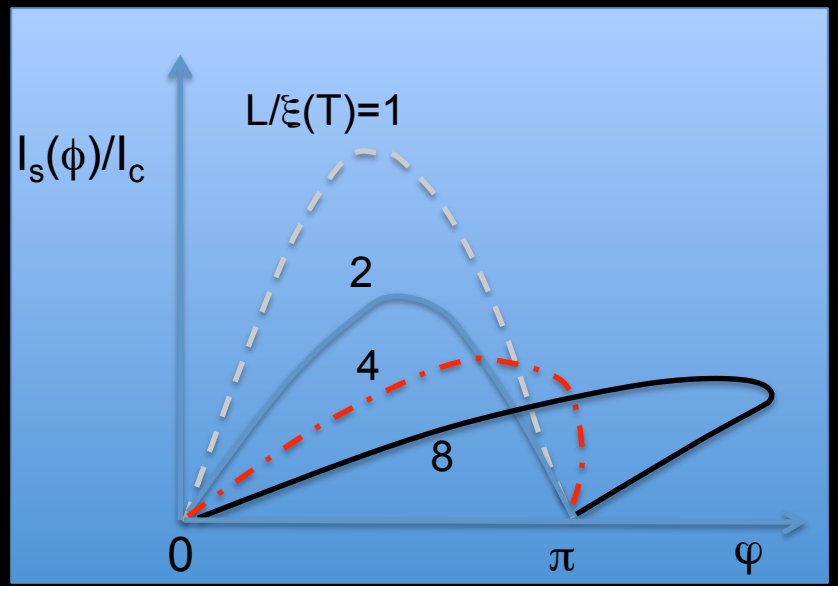


The Josephson effect: the general $I_c(\varphi)$ relation

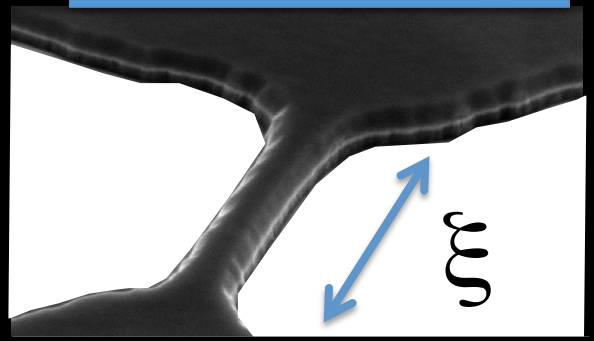
$$I_c(\varphi) = \sum_{n\geq 1} (I_n \sin(n\varphi) + J_n(\cos(n\varphi))$$

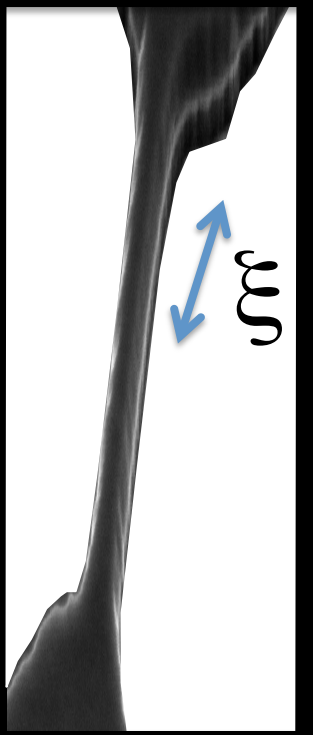






$$E_J(\varphi) = \frac{\hbar I_c}{2e}(1-\cos\varphi)$$



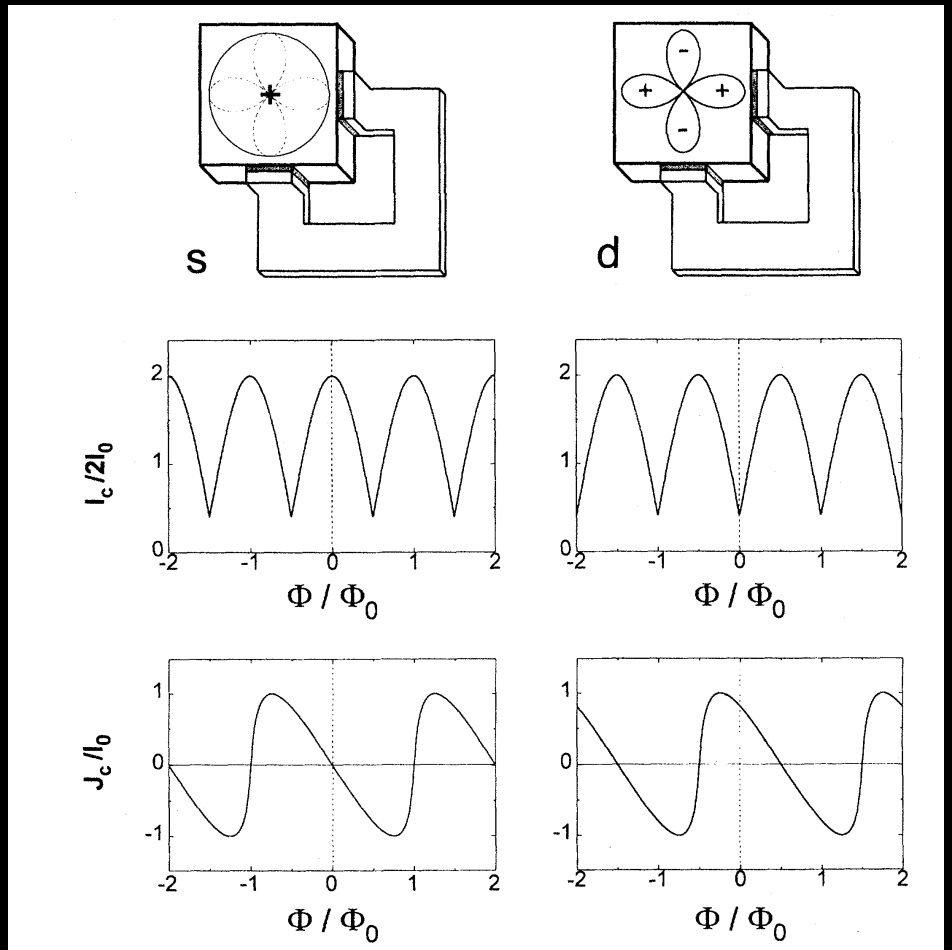


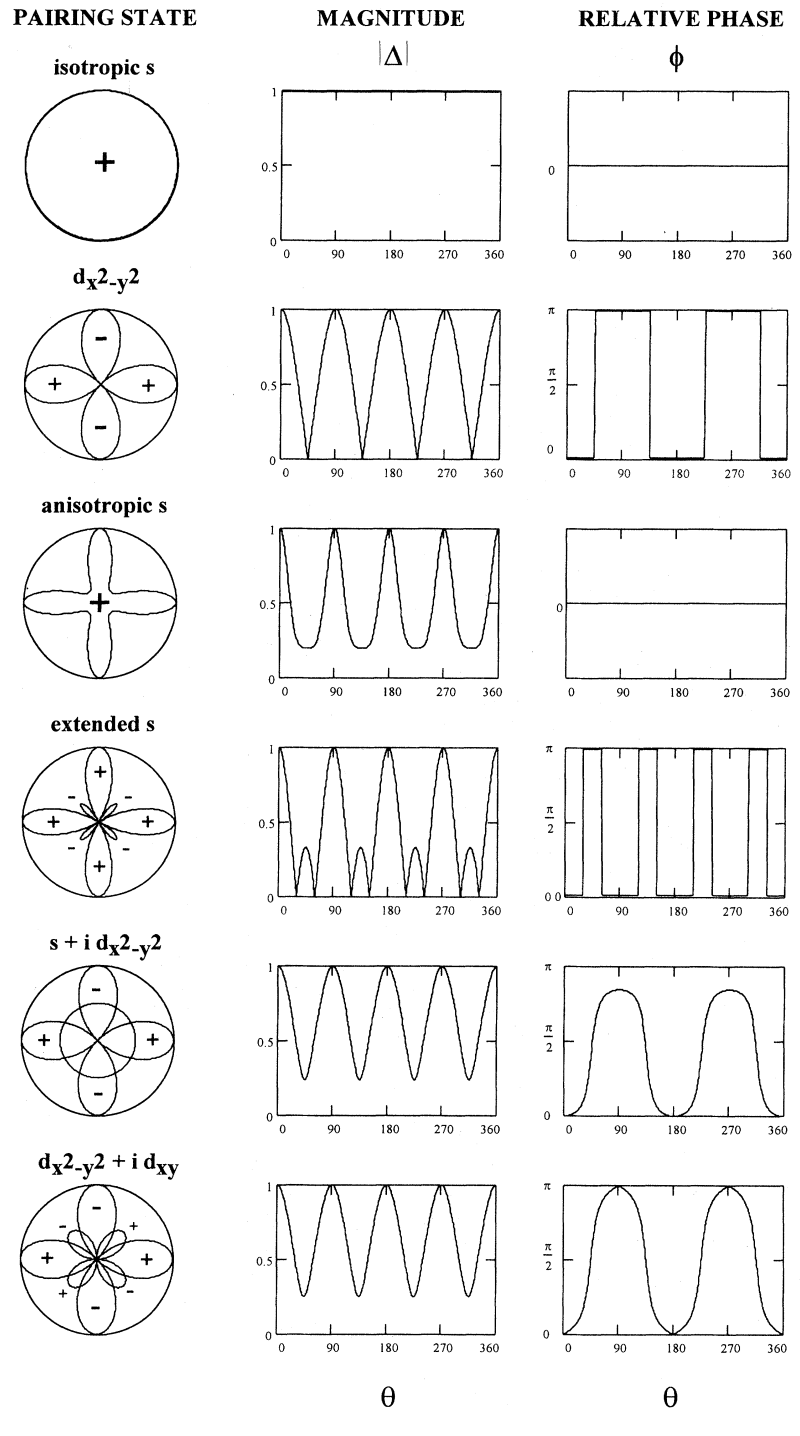
Phase-sensitive tests of the symmetry of the pairing state in the high-temperature superconductors—Evidence for $d_{x^2-y^2}$ symmetry

D. J. Van Harlingen

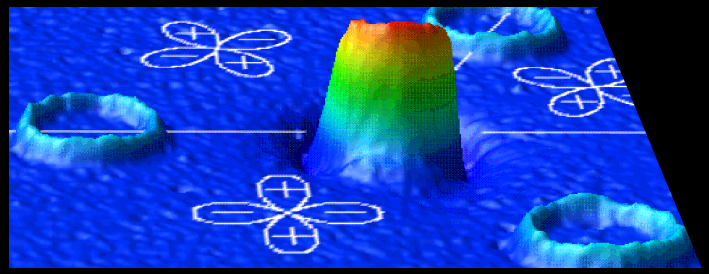
Department of Physics and Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801

Reviews of Modern Physics, Vol. 67, No. 2, April 1995

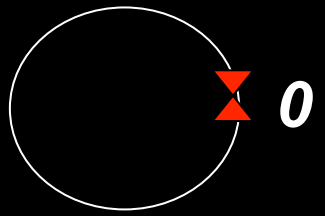




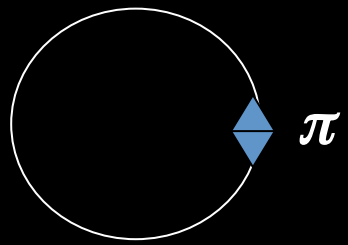
Half flux quantum effect in $YB_2C_3O_{7-x}$

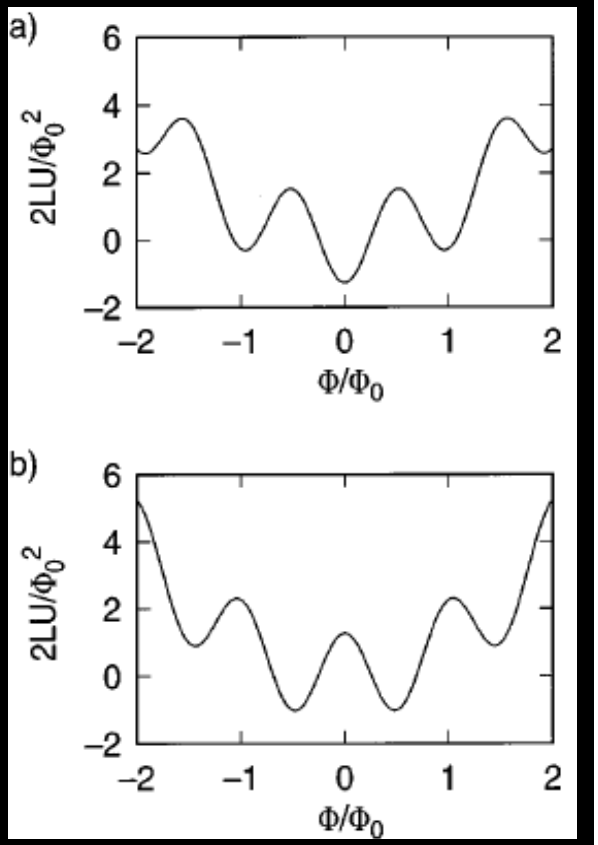


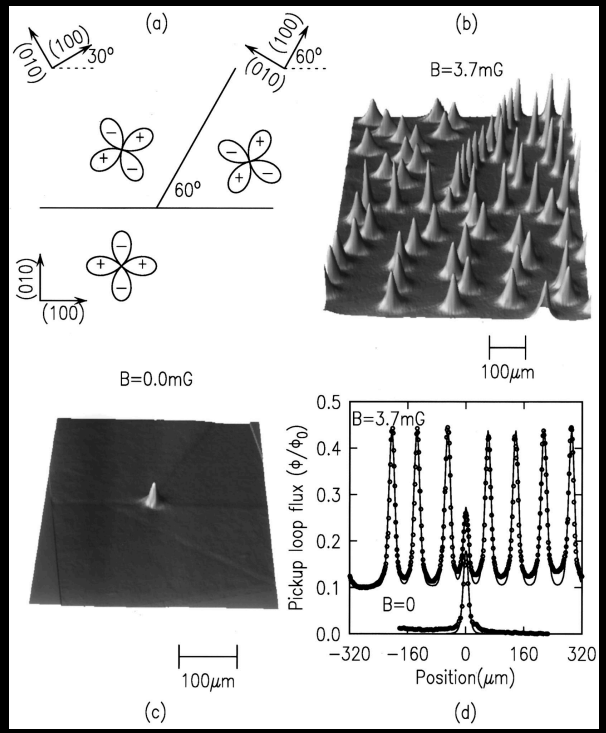
$I_C = I_{Co} \sin \varphi$



$I_C = I_{Co} \sin (\pi - \varphi)$



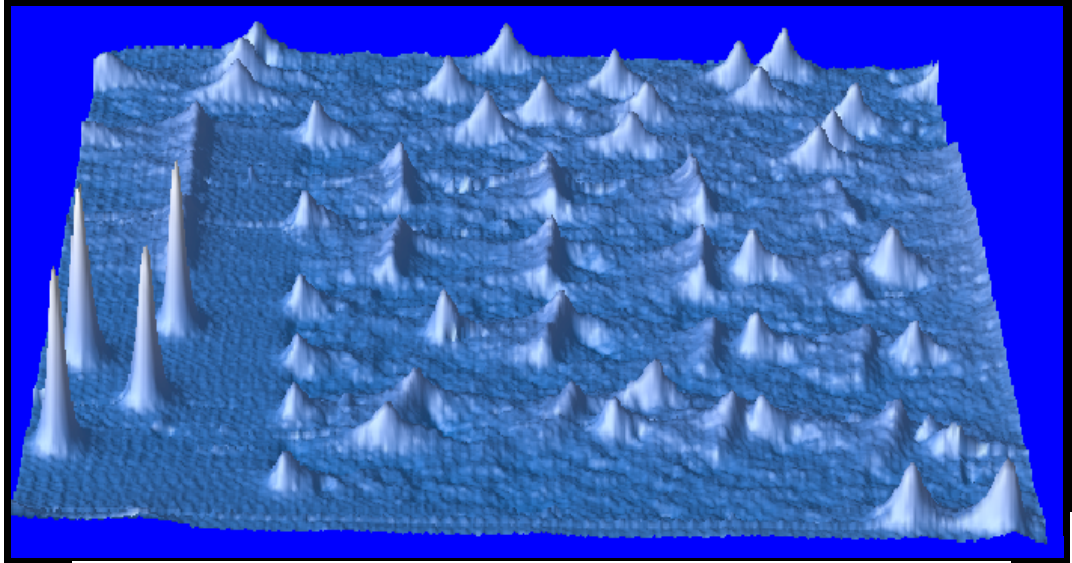


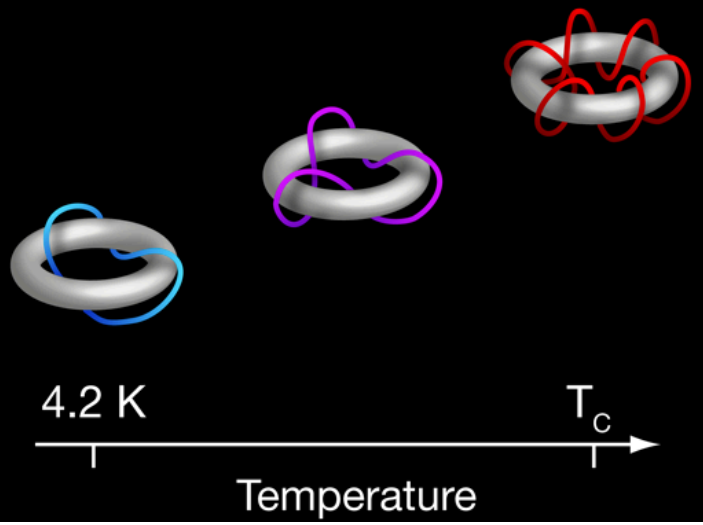


$$U(\Phi,\Phi_o) = \frac{\Phi_o^2}{2L}\left\{\left(\frac{\Phi-\Phi_a}{\Phi_o}\right)^2 - \left(\frac{L|I_c|}{\pi\Phi_o}\right)\times\cos\left[\frac{2\pi\Phi}{\Phi_o}+\phi\right]\right\}$$

C. Tsuei, J. Kirtley et al. PRL ('94)
J. Kirtley, C. Tsuei et al. Nature ('97)
C. Tsuei & J. Kirtley, RMP (2001)

L.N. Bulaevskii, V.V. Kuzii and A.A. Sobyanin, JETP Lett. 25, 290 (1977)
V.B. Geshkenbein, A.I. Larkin and A. Barone, Phys. Rev. B 36, 235 (1987)
M. Sigrist and T.M. Rice, J. Phys. Soc. Jpn. 61, 4283 (1992)





PHYSICAL REVIEW B **67**, 174516 (2003)

Intrinsic and extrinsic *d*-wave effects in $YBa_2Cu_3O_{7-\delta}$ grain boundary Josephson junctions: Implications for π circuitry

F. Tafuri,[1,2] J. R. Kirtley,[2] F. Lombardi,[3,4] and F. Miletto Granozio[3]

VOLUME 90, NUMBER 25 PHYSICAL REVIEW LETTERS week ending 27 JUNE 2003

Thermally Activated Spontaneous Fluxoid Formation in Superconducting Thin Film Rings

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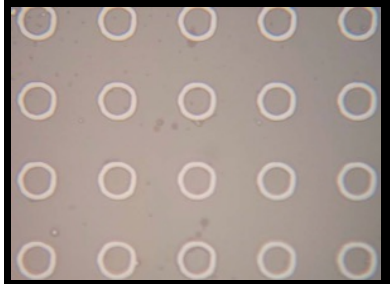
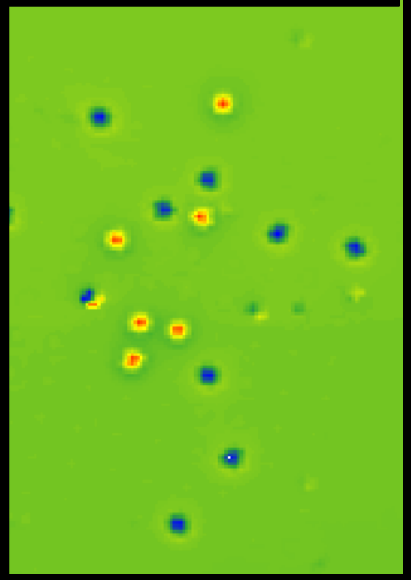
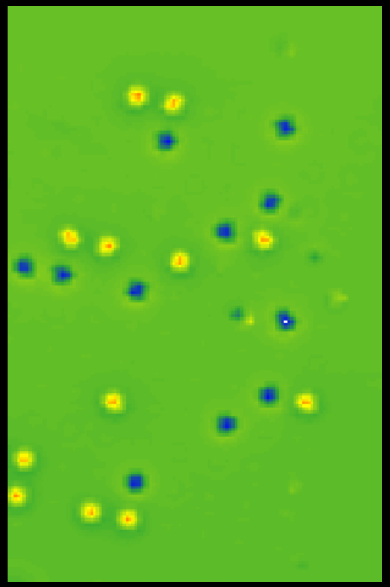
(Received 19 February 2003; published 26 June 2003)

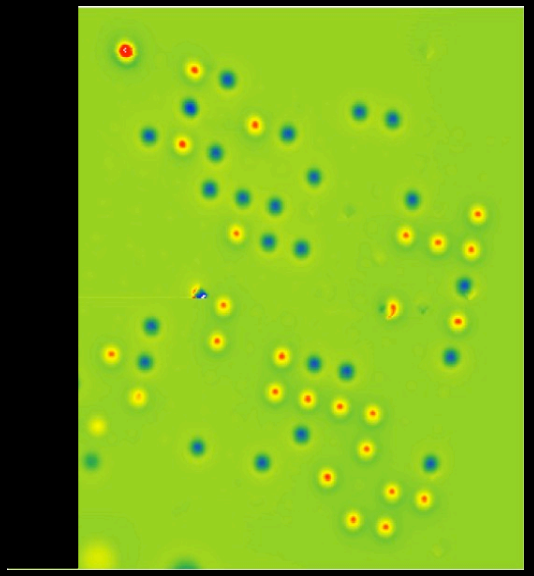




2.1x10^{-4} K/sec

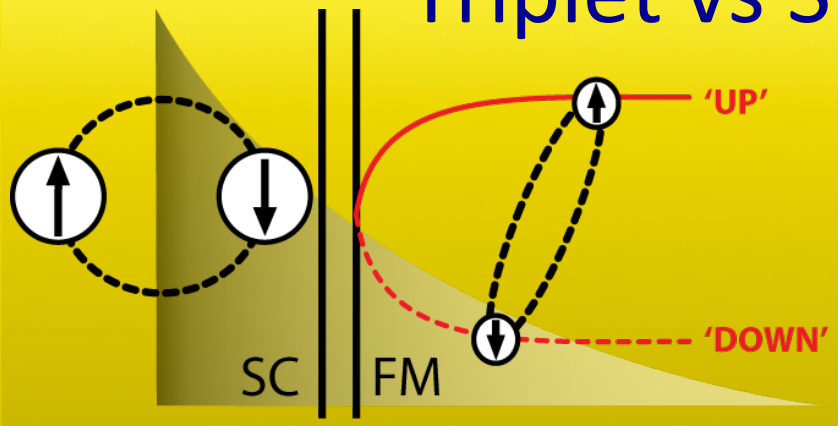


9.2x10^{-3} K/sec



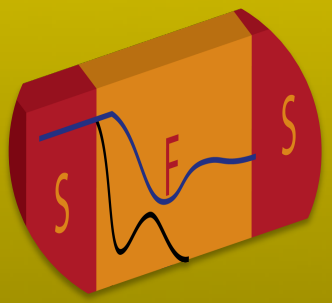
21 K/sec

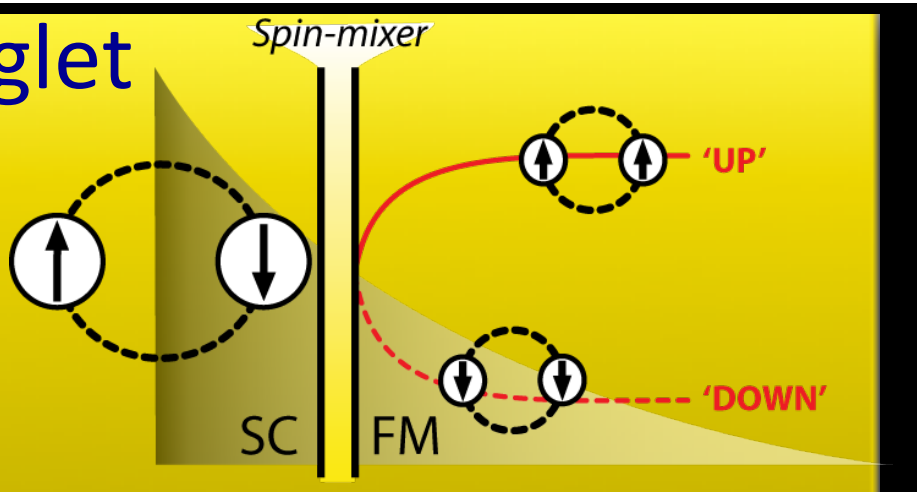
Triplet vs Singlet



$$\xi_{F2} = \sqrt{\left(\mathrm{h}D/E_{ex}(T)\right)} \sim 1nm$$

★ Anti-Parallel spin pairing





$$\xi_{F2} = \sqrt{\left(\mathrm{h}D/T\right)} >> 1nm$$

★ Parallel spin pairing
★ Even in momentum
★ Odd in frequency
★ Net spin!

Odd triplet superconductivity and related phenomena
in superconductor-ferromagnet structures
F. S. Bergeret, A. F. Volkov &K. B. Efetov RMP 77, 1321 (2005)

Emerging field of hybrid JJs

Hybrid Josepshon junctions using barriers with complementary functionalities (semiconductors, ferromagnets, topological insulators, graphene… also as flakes and nanowires) may provide multitasking capabilities.

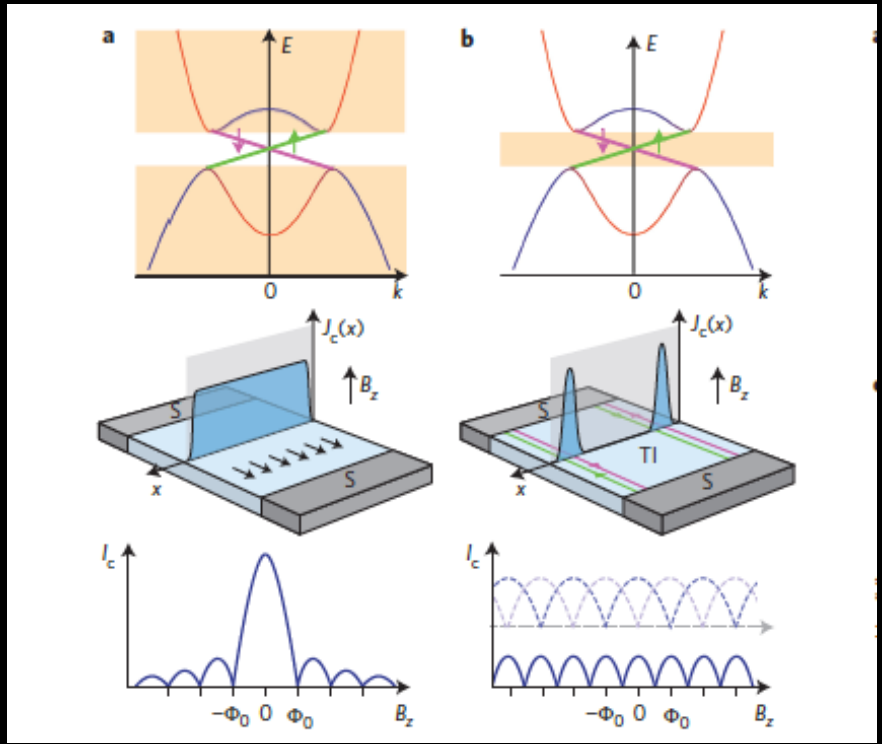
nature nanotechnology

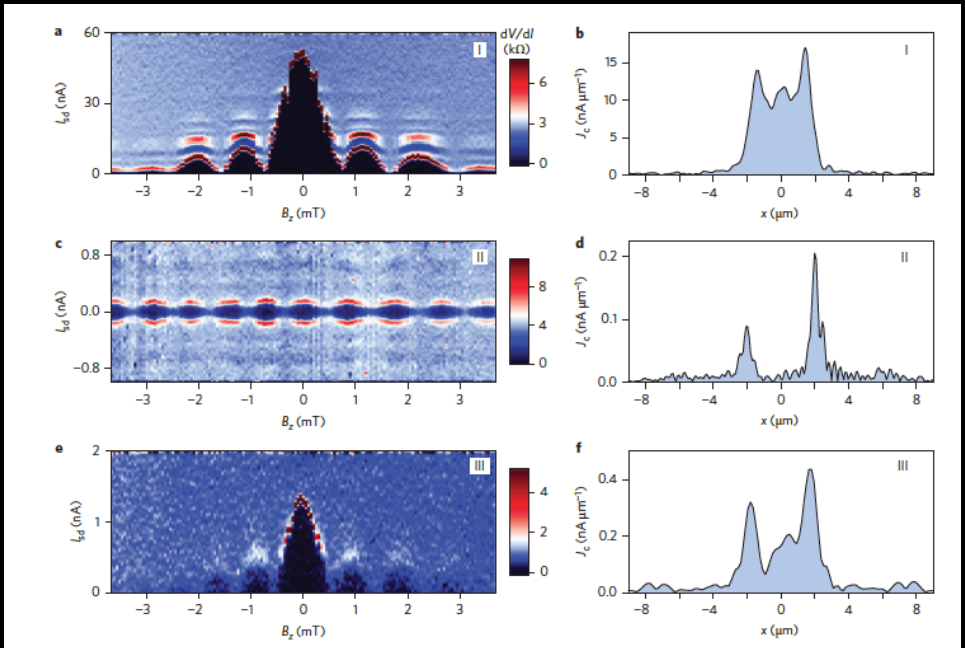
LETTERS

PUBLISHED ONLINE: 11 MAY 2015 | DOI: 10.1038/NNANO.2015.86

Edge-mode superconductivity in a two-dimensional topological insulator

Vlad S. Pribiag[1†‡], Arjan J. A. Beukman[1‡], Fanming Qu[1‡], Maja C. Cassidy[1], Christophe Charpentier[2], Werner Wegscheider[2] and Leo P. Kouwenhoven[1*]





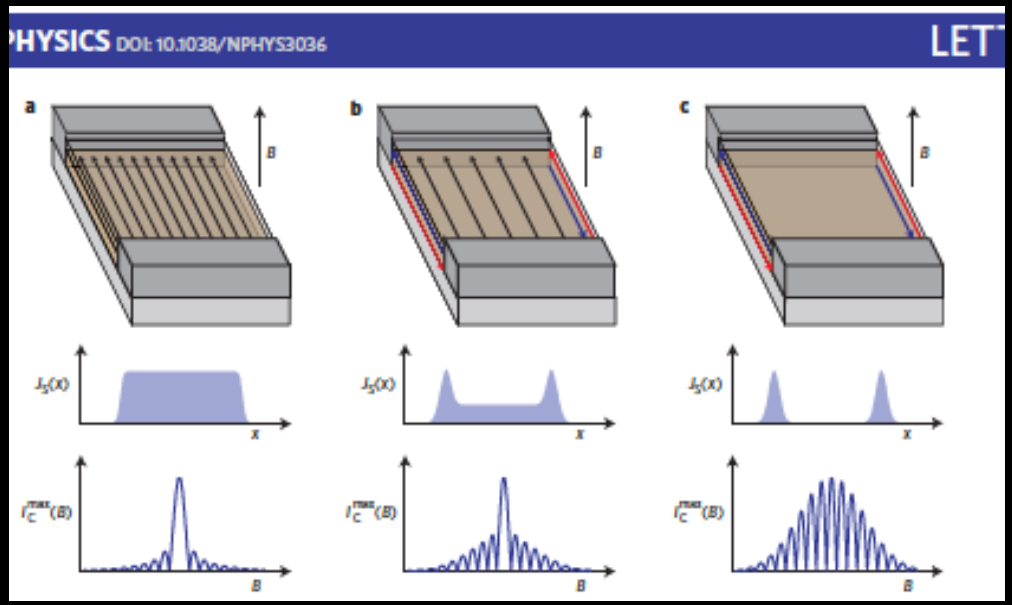
Emerging field of hybrid JJs

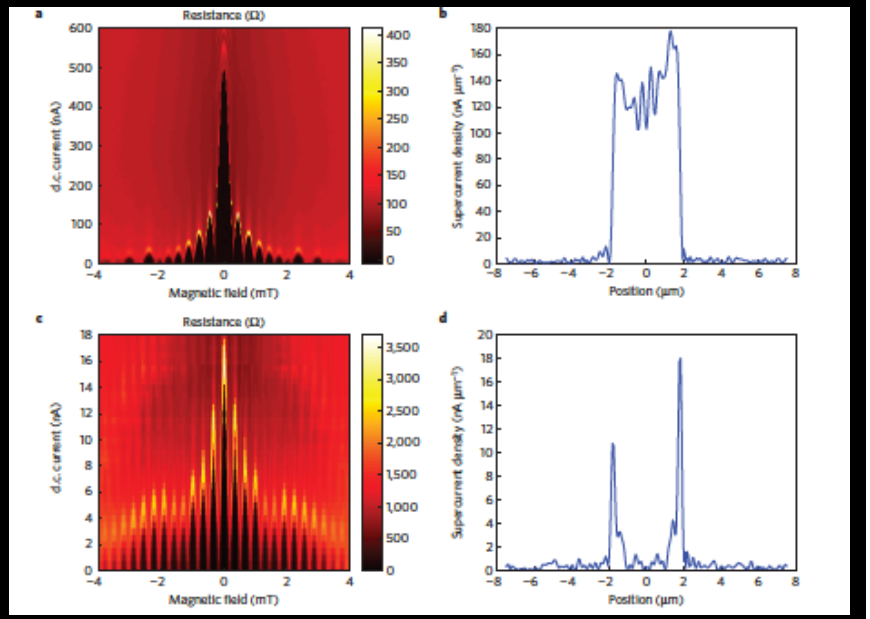
Hybrid Josepshon junctions using barriers with complementary functionalities (semiconductors, ferromagnets, topological insulators, graphene… also as flakes and nanowires) may provide multitasking capabilities.

LETTERS
PUBLISHED ONLINE: 3 AUGUST 2014 | DOI: 10.1038/NPHYS3036
nature physics

Induced superconductivity in the quantum spin Hall edge

Sean Hart[1†], Hechen Ren[1†], Timo Wagner[1], Philipp Leubner[2], Mathias Mühlbauer[2], Christoph Brüne[2], Hartmut Buhmann[2], Laurens W. Molenkamp[2] and Amir Yacoby[1*]





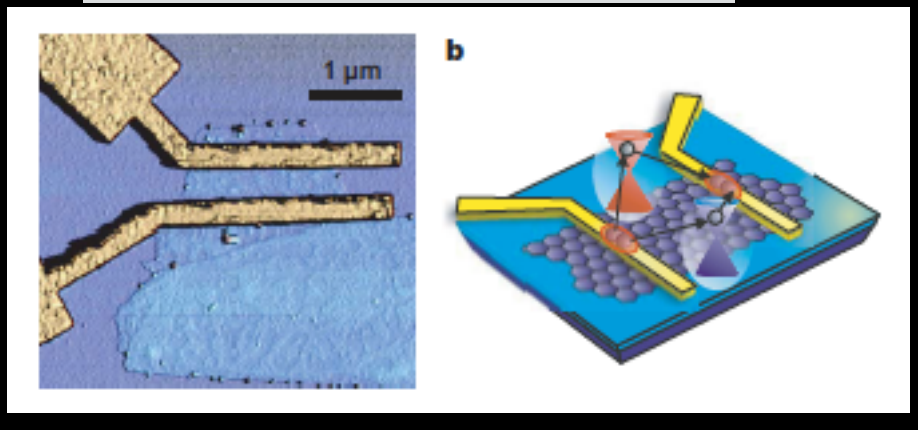
Emerging field of hybrid JJs

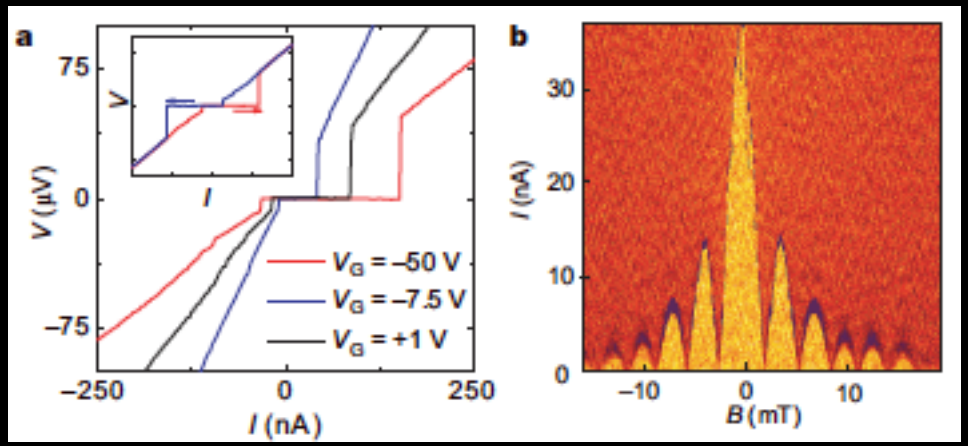
Hybrid Josepshon junctions using barriers with complementary functionalities (semiconductors, ferromagnets, topological insulators, graphene… also as flakes and nanowires) may provide multitasking capabilities.

Bipolar supercurrent in graphene

Hubert B. Heersche[1]*, Pablo Jarillo-Herrero[1]*, Jeroen B. Oostinga[1], Lieven M. K. Vandersypen[1] & Alberto F. Morpurgo[1]

Vol 446|1 March 2007|doi:10.1038/nature05555



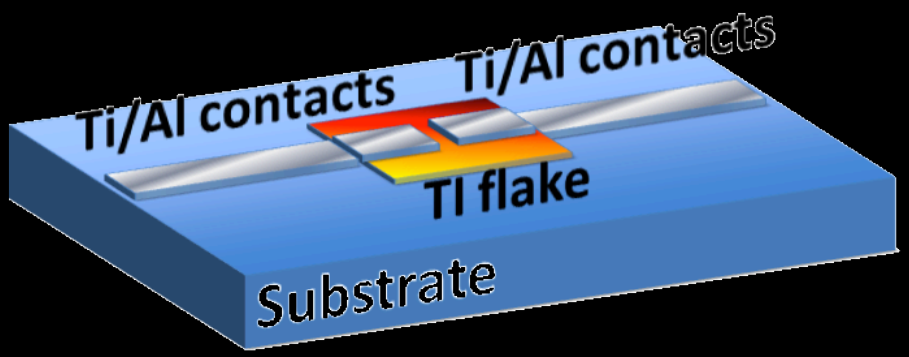


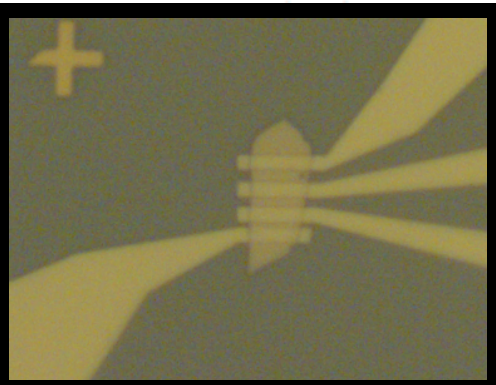
A comparative analysis flakes-based TI and graphene and LAO/STO

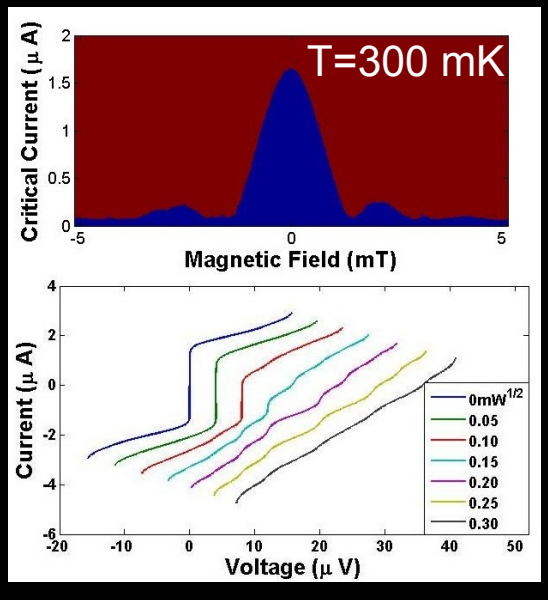
PHYSICAL REVIEW B **89**, 134512 (2014)

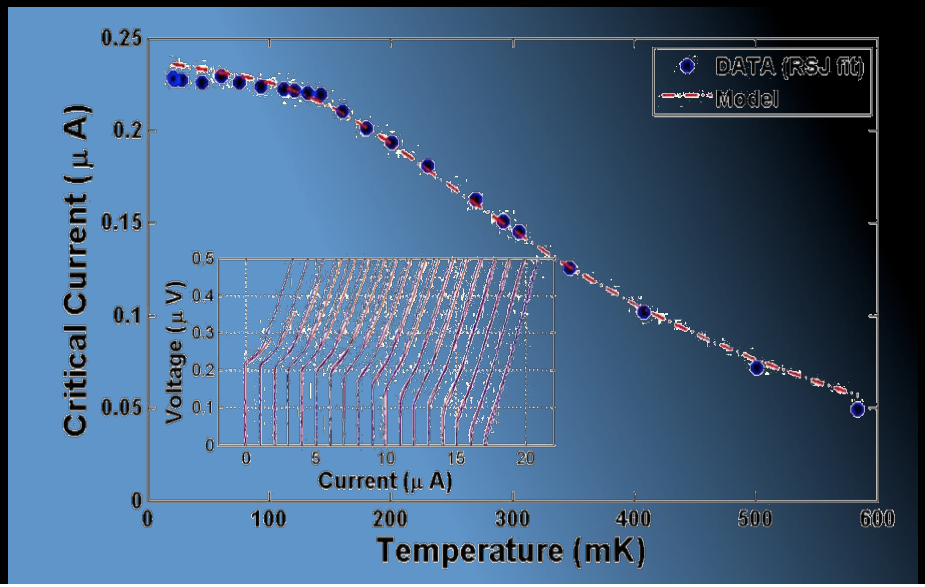
Influence of topological edge states on the properties of Al/Bi_2Se_3/Al hybrid Josephson devices

L. Galletti,[1,2,*] S. Charpentier,[3] M. Iavarone,[4] P. Lucignano,[1,2] D. Massarotti,[1,2] R. Arpaia,[2,1,3] Y. Suzuki,[5] K. Kadowaki,[5] T. Bauch,[3] A. Tagliacozzo,[1] F. Tafuri,[2,6] and F. Lombardi[3]







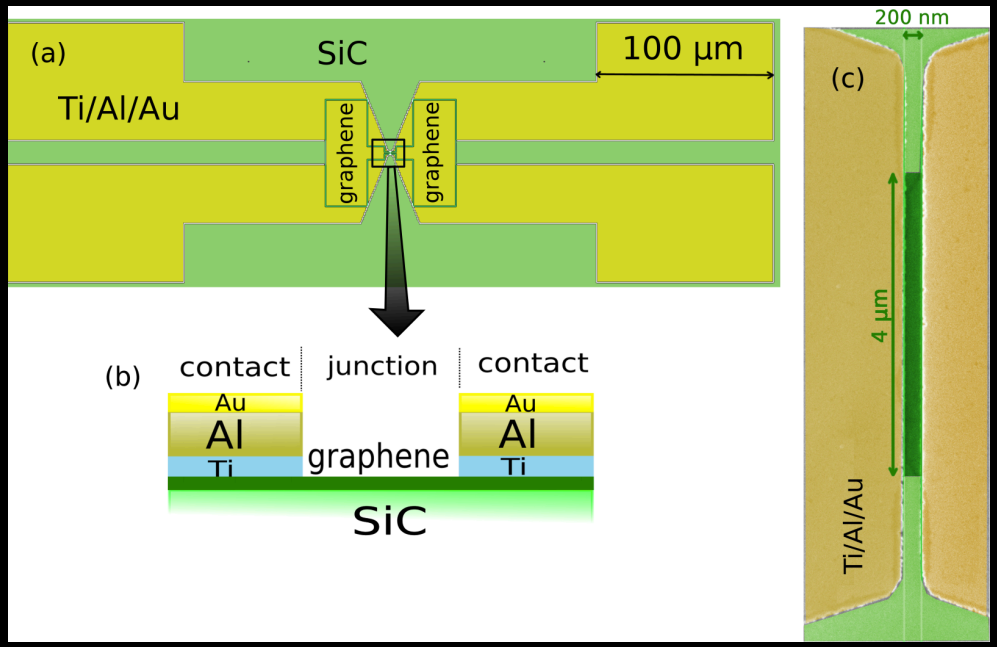


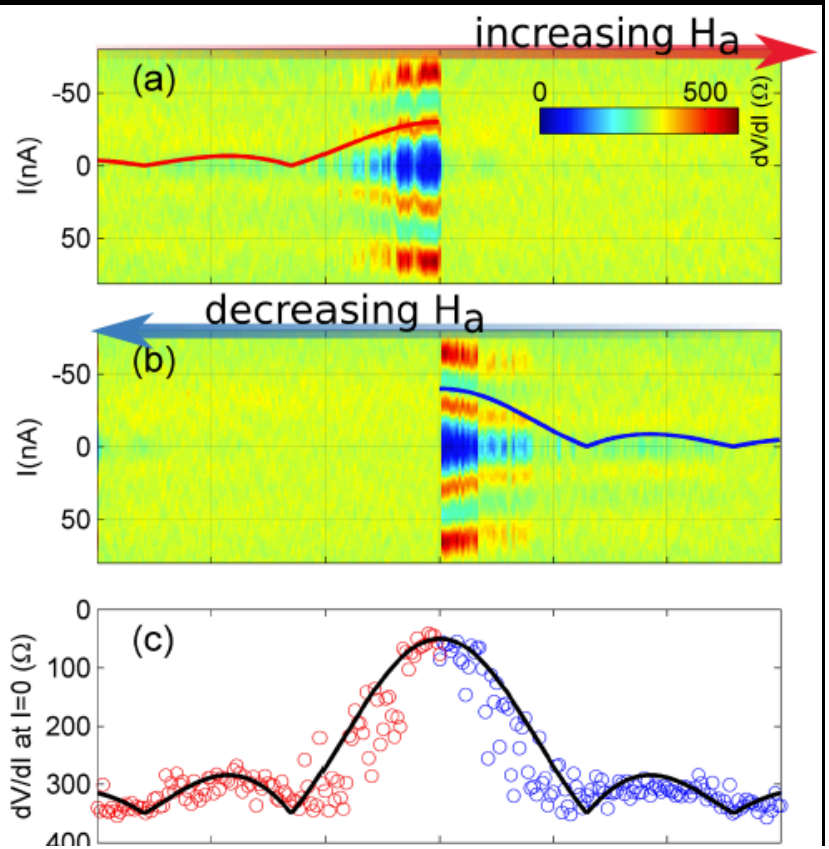
A comparative analysis flakes-based TI and graphene and LAO/STO

PHYSICAL REVIEW B **94**, 054525 (2016)

Incipient Berezinskii-Kosterlitz-Thouless transition in two-dimensional coplanar Josephson junctions

D. Massarotti,[1,2,*] B. Jouault,[3] V. Rouco,[4] S. Charpentier,[5] T. Bauch,[5] A. Michon,[6] A. De Candia,[2,4] P. Lucignano,[2,4] F. Lombardi,[5] F. Tafuri,[1,2] and A. Tagliacozzo[2,4,7]





Hysteretic collapse and revival of the Josephson current

A comparative analysis flakes-based TI and graphene and LAO/STO

RAPID COMMUNICATIONS

PHYSICAL REVIEW B 95, 140502(R) (2017)

Signatures of unconventional superconductivity in the $LaAlO_3/SrTiO_3$ two-dimensional system

D. Stornaiuolo,[1,2,*] D. Massarotti,[1,2] R. Di Capua,[1,2] P. Lucignano,[2] G. P. Pepe,[1,2] M. Salluzzo,[2] and F. Tafuri[3]

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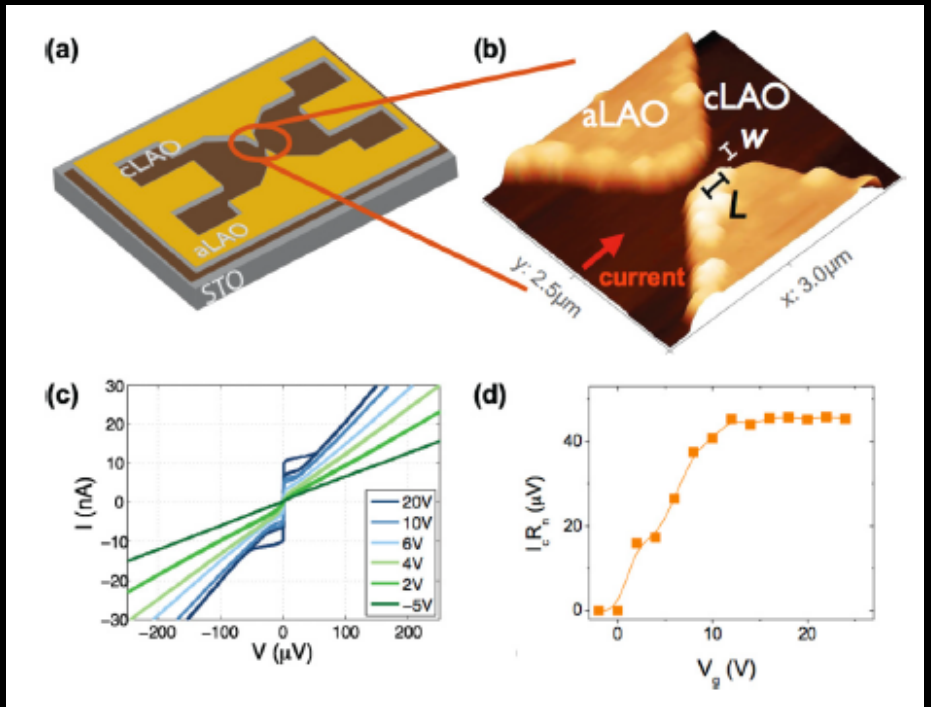
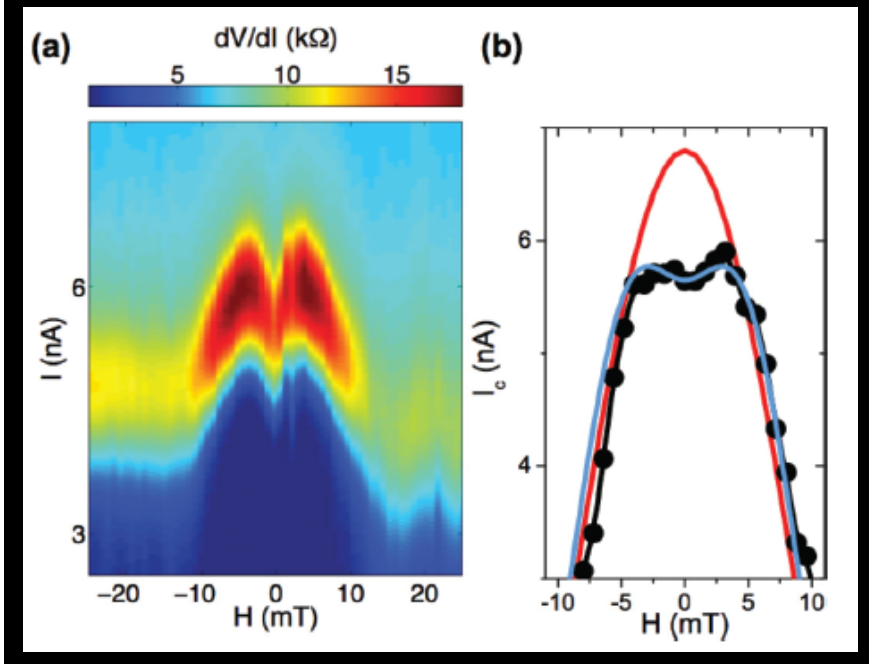
[2]*CNR-SPIN UOS Napoli, Monte S. Angelo-Via Cintia, I-80126, Napoli, Italy*

[3]*Dipartimento di Ingegneria Industriale e dell'Informazione, Seconda Università di Napoli, I-81031 Aversa (CE), Italy*

(Received 19 January 2017; published 7 April 2017)

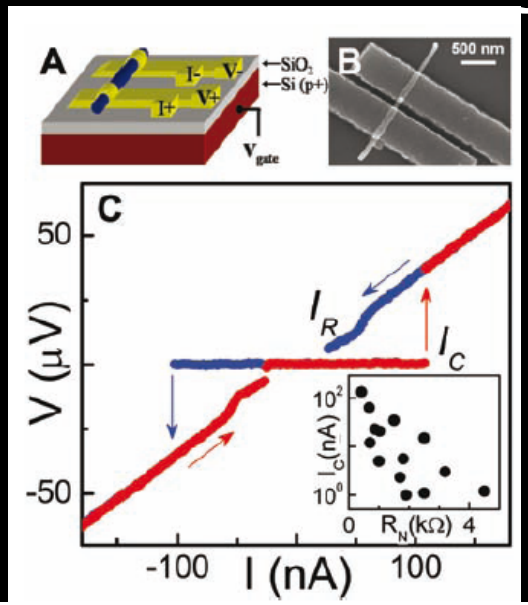
We study the superconducting state of the two-dimensional electron gas (2DEG) at the $LaAlO_3/SrTiO_3$ interface using Josephson junctions as spectroscopic probes. The transport properties of these devices reveal the presence of two superconducting gap structures and of an unconventional superconducting π channel. These features provide evidence of an unconventional superconducting ground state, possibly related to the interplay between superconductivity and the large Rashba spin-orbit coupling in the 2DEG.





A comparative analysis of different I-V

Looking at the switch: transition from S to N



8 JULY 2005 VOL 309 SCIENCE

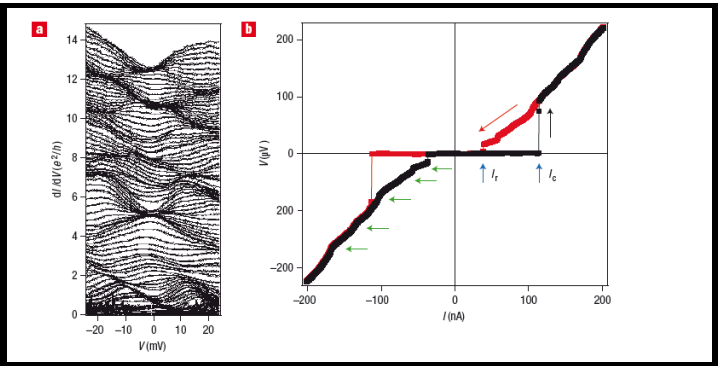
Tunable Supercurrent Through Semiconductor Nanowires

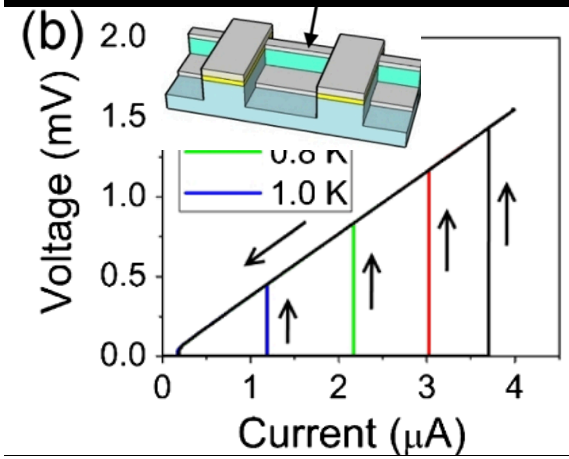
Yong-Joo Doh,[1*] Jorden A. van Dam,[1*] Aarnoud L. Roest,[1,2] Erik P. A. M. Bakkers,[2] Leo P. Kouwenhoven,[1] Silvano De Franceschi[1†]

ARTICLES

Ge/Si nanowire mesoscopic Josephson junctions

JIE XIANG[1], A. VIDAN[2*], M. TINKHAM[2,3], R. M. WESTERVELT[2,3†] AND CHARLES M. LIEBER[1,2†]





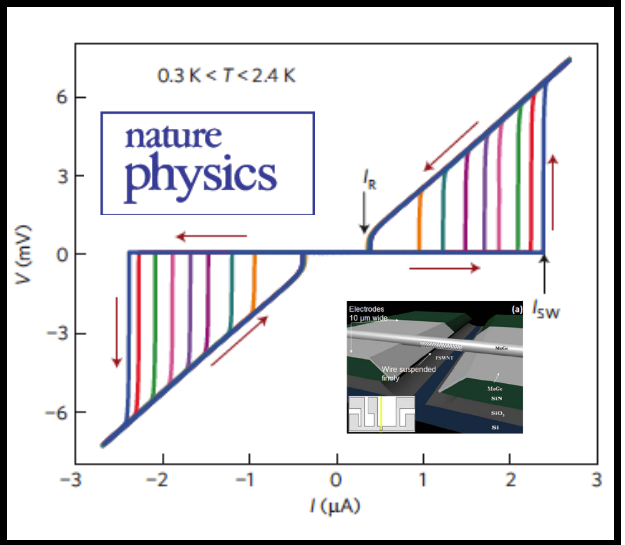
PRL 107, 137004 (2011) PHYSICAL REVIEW LETTERS week ending 23 SEPTEMBER 2011

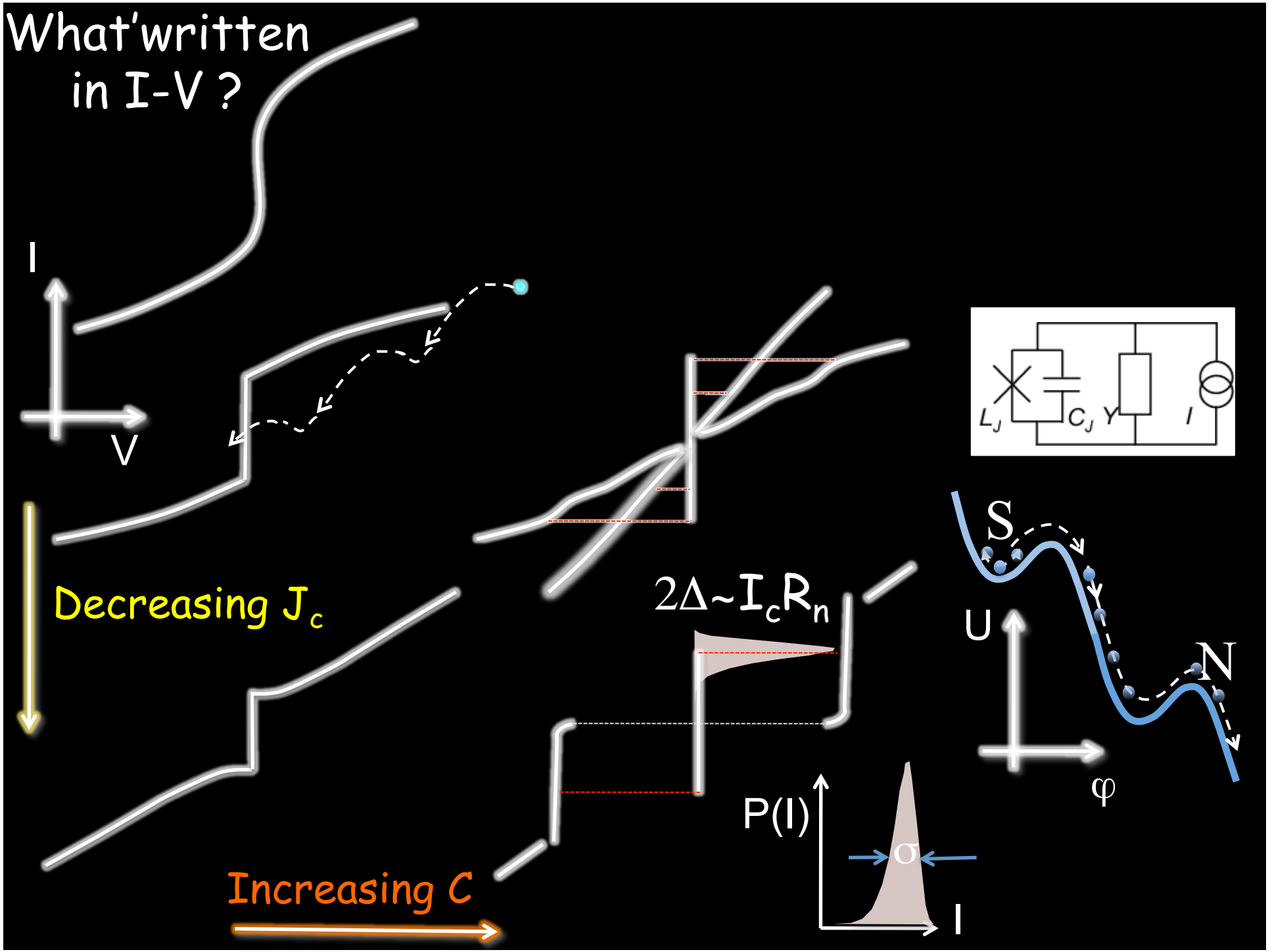
Switching Currents Limited by Single Phase Slips in One-Dimensional Superconducting Al Nanowires

Peng Li, Phillip M. Wu, Yuriy Bomze, Ivan V. Borzenets, Gleb Finkelstein, and A. M. Chang*

Individual topological tunnelling events of a quantum field probed through their macroscopic consequences

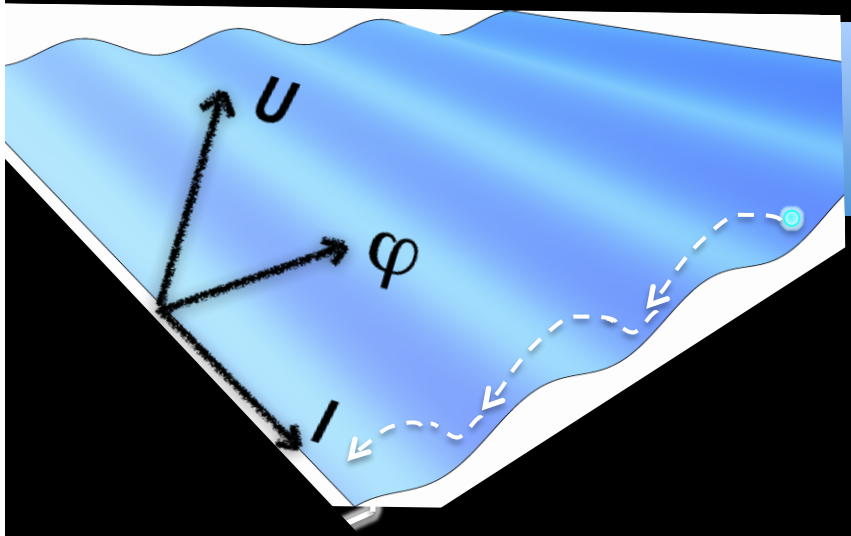
Mitrabhanu Sahu[1*], Myung-Ho Bae[1], Andrey Rogachev[1,2], David Pekker[1,3], Tzu-Chieh Wei[1,4], Nayana Shah[1], Paul M. Goldbart[1] and Alexey Bezryadin[1]




What'written
in I-V ?
I
V
Decreasing J_c
Increasing C
$2\Delta \sim I_c R_n$
P(I)
σ
I
L_J
C_J
Y
I
S
N
U
φ

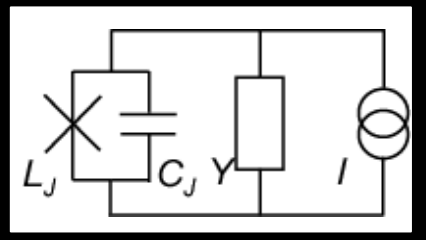
What'written in I-V ?

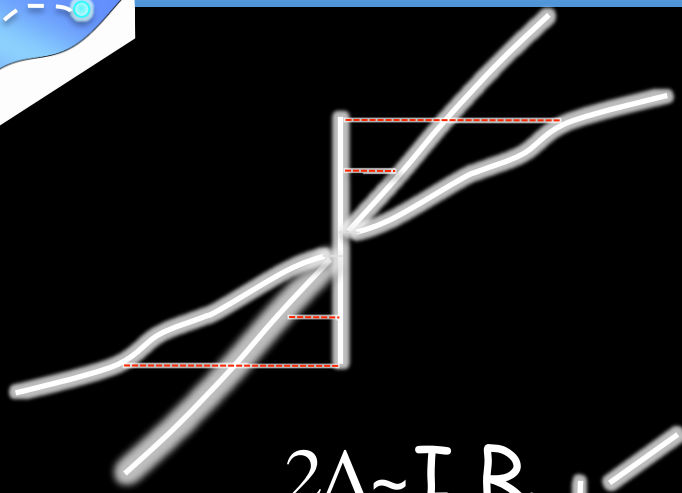
$$\left(\frac{\phi_o}{2\pi}\right)^2 C\frac{\partial^2\varphi}{\partial t^2}+\left(\frac{\phi_o}{2\pi}\right)^2\frac{1}{R}\frac{\partial\varphi}{\partial t}+\frac{\partial U(\varphi,I)}{\partial\varphi}=0$$

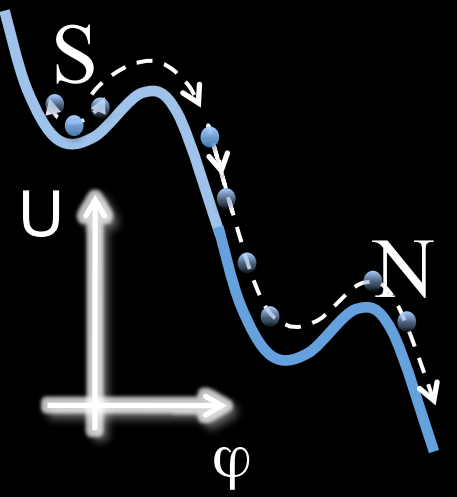


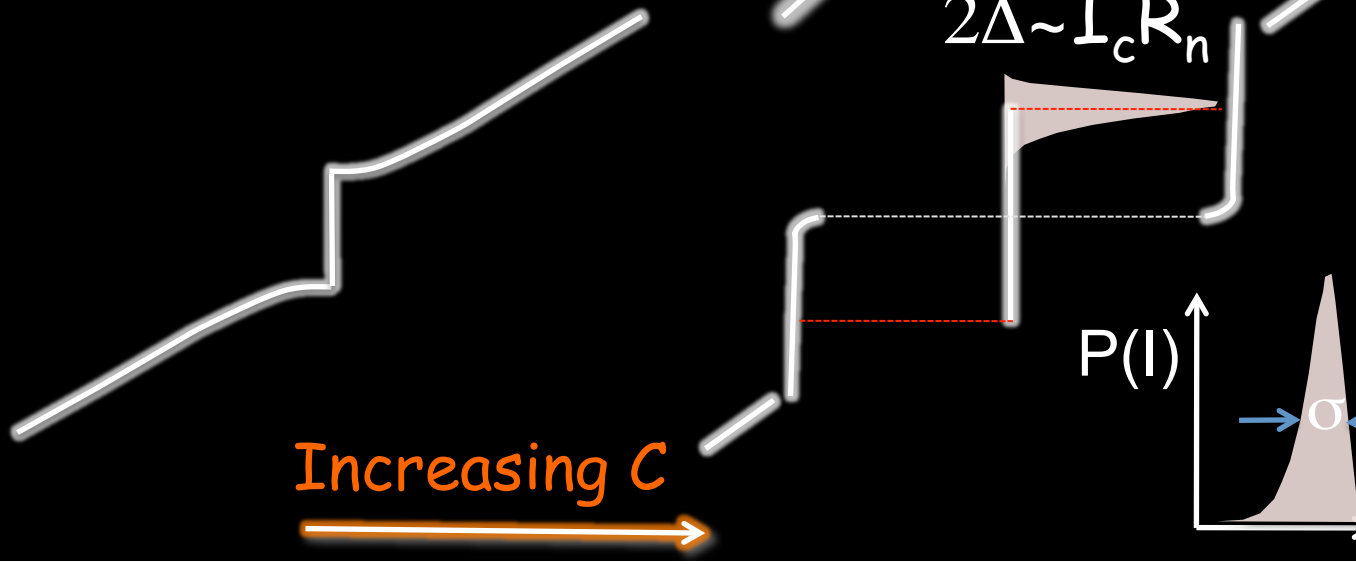
$$U(\varphi,I)=E_J\left(-\frac{I}{I_c}\varphi-\cos(\varphi)\right)$$

$$E_J=\frac{I_c\Phi_o}{2\pi}$$

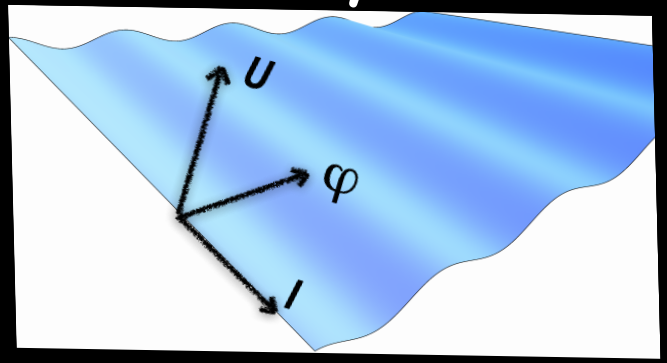


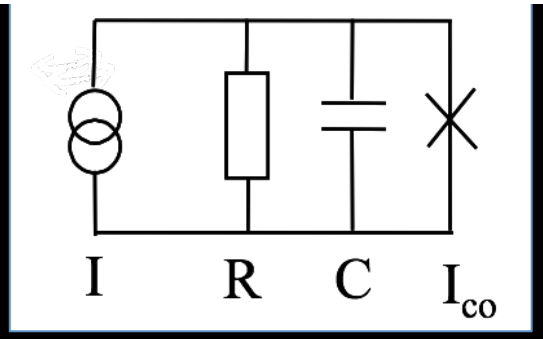






Phase dynamics

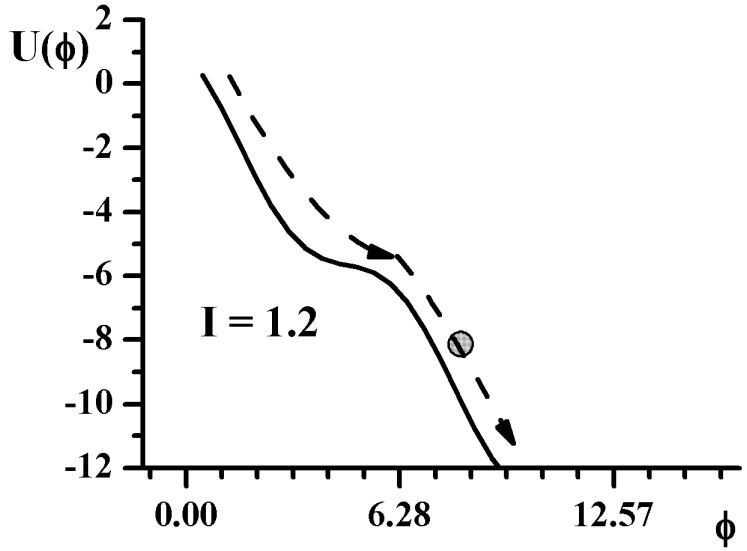


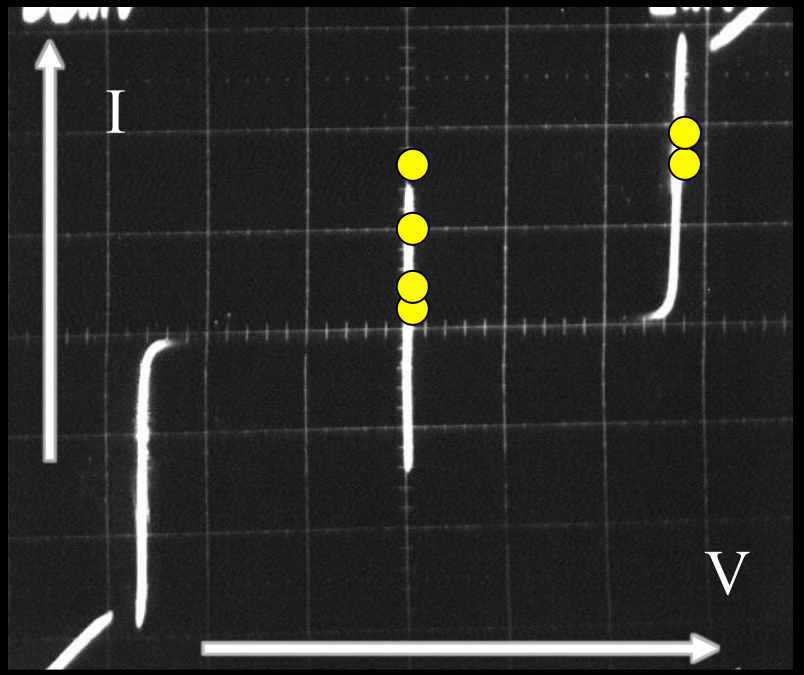


$$I = C\frac{dV(t)}{dt} + GV(t) + I_c \sin\varphi(t)$$

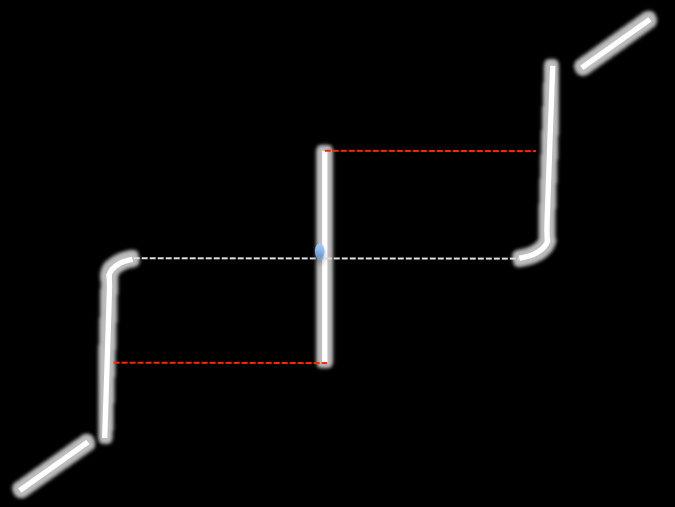
$$\left(\frac{\phi_o}{2\pi}\right)^2 C\frac{\partial^2\varphi}{\partial t^2} + \left(\frac{\phi_o}{2\pi}\right)^2 \frac{1}{R}\frac{\partial\varphi}{\partial t} + \frac{\partial U(\varphi, I)}{\partial\varphi} = 0$$

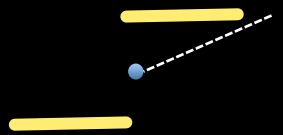
$$U(\varphi, I) = E_J\left(-\frac{I}{I_c}\varphi - \cos(\varphi)\right)$$





What is written in I-V?





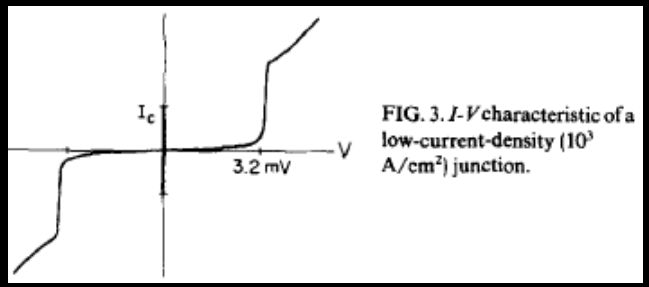


FIG. 3. *I-V* characteristic of a low-current-density (10^3 A/cm^2) junction.

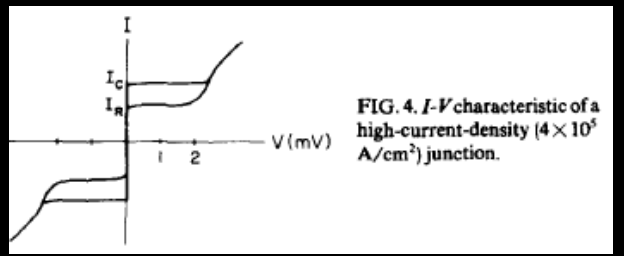


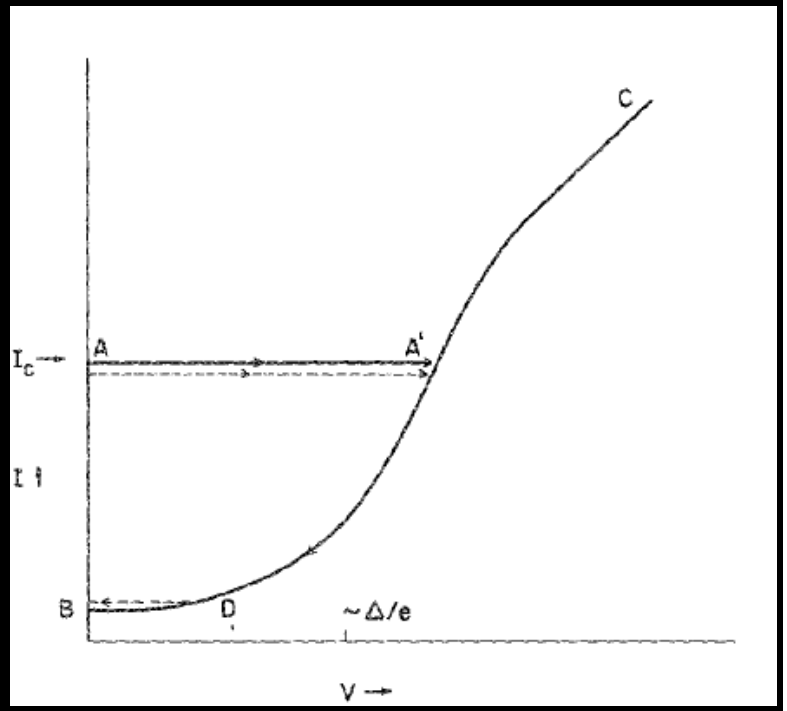
FIG. 4. *I-V* characteristic of a high-current-density (4×10^5 A/cm^2) junction.

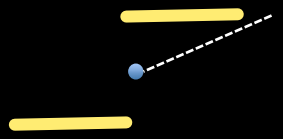
High-quality submicron niobium tunnel junctions with reactive-ion-beam oxidation

A. W. Kleinsasser and R. A. Buhrman
School of Applied and Engineering Physics, Materials Science Center, and National Research and Resource Facility for Submicron Structures, Cornell University, Ithaca, New York 14853

841 Appl. Phys. Lett. **37**(9), 1 November 1980

What is written in I-V?





The return of a hysteretic Josephson junction to the zero-voltage state: *I-V* characteristic and quantum retrapping

Y. C. Chen[a)]
Department of Physics, University of Illinois at Urbana-Champaign, 1110 West Green Street, Urbana, Illinois 61801

Matthew P. A. Fisher
IBM Research Division, Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598

A. J. Leggett
Department of Physics, University of Illinois at Urbana-Champaign, 1110 West Green Street, Urbana, Illinois 61801

$$\Gamma_t = a_t \frac{\omega_P}{2\pi} \exp\left(-\frac{\Delta U}{k_B T}\right)$$

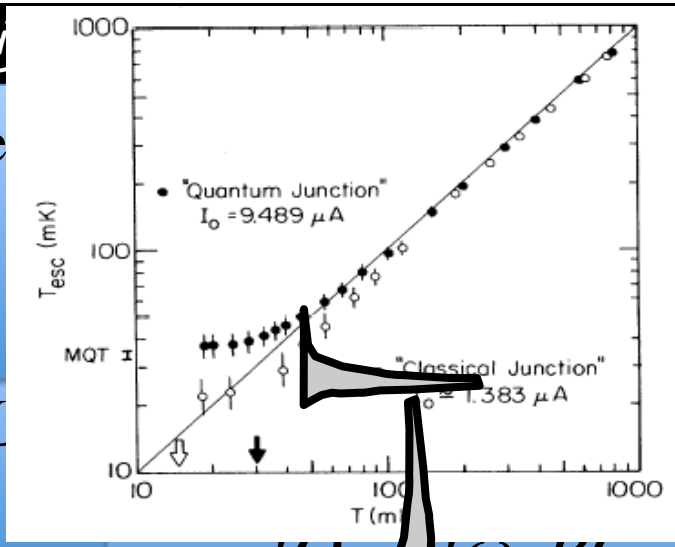
Kramers, Physica 7, 284 (1940)

Caldeira & L

$$\Gamma_q = A e$$

$$A = \frac{\omega_P}{2\pi}$$

$$\Gamma \quad \Delta U$$



M.H. Devoret, J.M. Marti[illegible] and J. Clarke, Phys. Rev. Lett. 55, 1908 (1985)

U

TA

MQT

Γ_0

$$\omega_P = \frac{1}{\sqrt{L_J C_J}} = \left(\frac{2\pi I_c}{\phi_o C}\right)^{1/2} \left(1 - \left(\frac{I}{I_c}\right)^2\right)^{1/4}$$

$$T_{cr} = \frac{h\omega_p}{2\pi\, k_B} \left\{ \left[1 + \left(\frac{1}{2Q}\right)^2\right]^{1/2} - \frac{1}{2Q} \right\}$$

φ

10 mK

P(I)

600 mK

σ

I

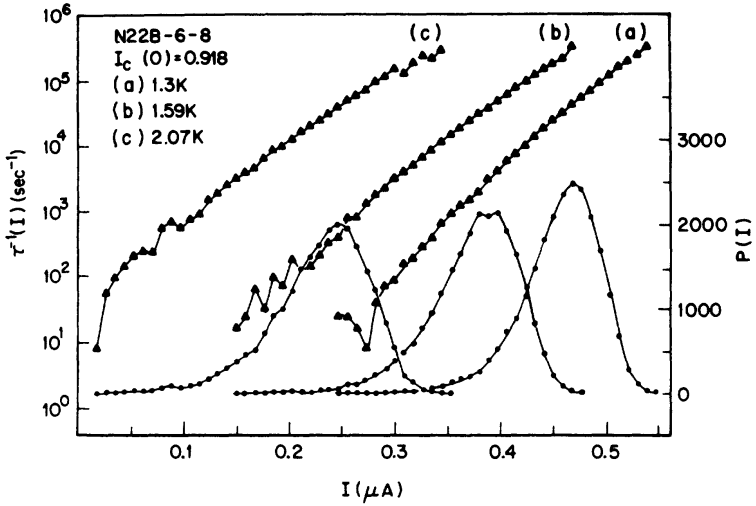
TA

T_{bath}

PHYSICAL REVIEW B VOLUME 9, NUMBER 11 1 JUNE 1974

Lifetime of the zero-voltage state in Josephson tunnel junctions

T. A. Fulton and L. N. Dunkleberger
Bell Laboratories, Murray Hill, New Jersey 07974
(Received 29 October 1973)



VOLUME 47, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JULY 1981

Macroscopic Quantum Tunneling in 1-μm Nb Josephson Junctions

Richard F. Voss and Richard A. Webb
IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598
(Received 24 April 1981)

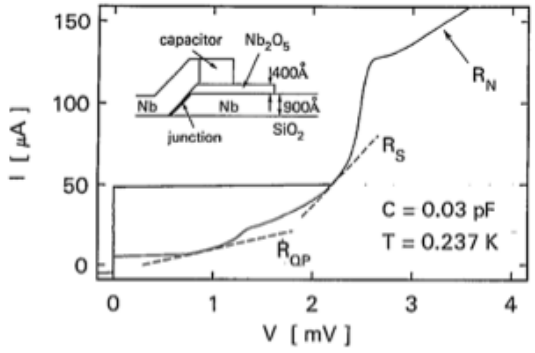
VOLUME 47, NUMBER 9 PHYSICAL REVIEW LETTERS 31 AUGUST 1981

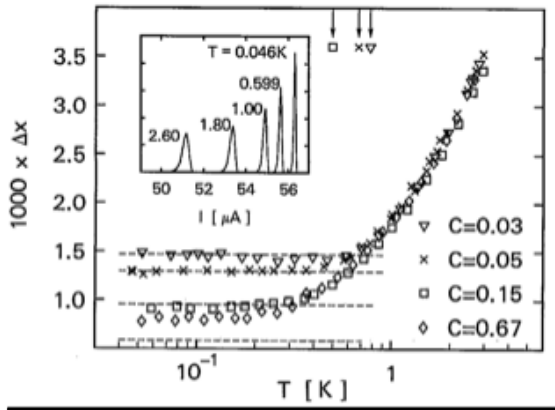
Decay of the Zero-Voltage State in Small-Area, High-Current-Density Josephson Junctions

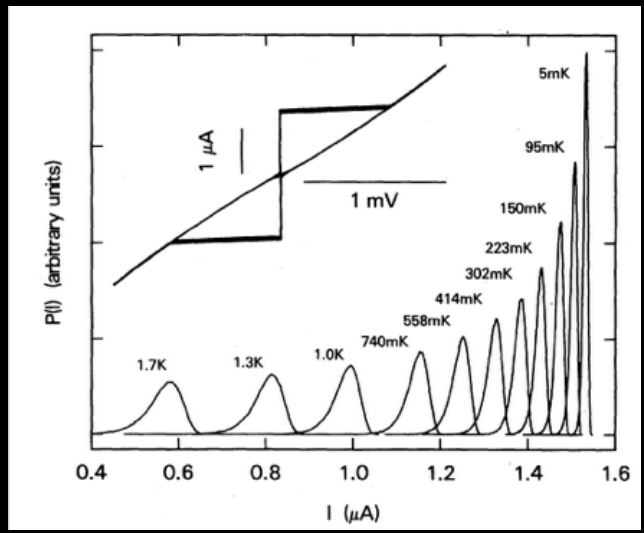
L. D. Jackel, J. P. Gordon, E. L. Hu, R. E. Howard, L. A. Fetter,
D. M. Tennant, and R. W. Epworth
Bell Laboratories, Holmdel, New Jersey 07733

and

J. Kurkijärvi



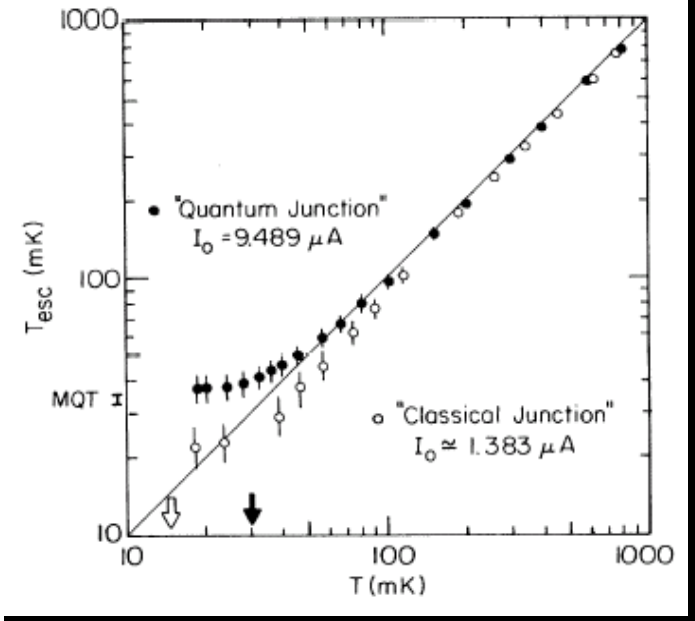


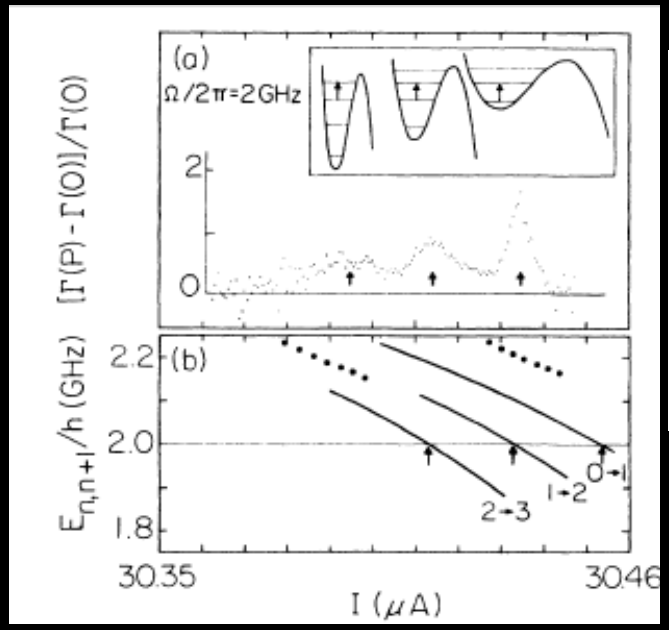


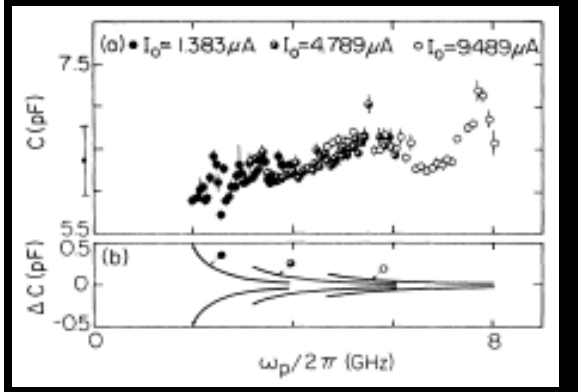
VOLUME 55, NUMBER 18 PHYSICAL REVIEW LETTERS 28 OCTOBER 1985

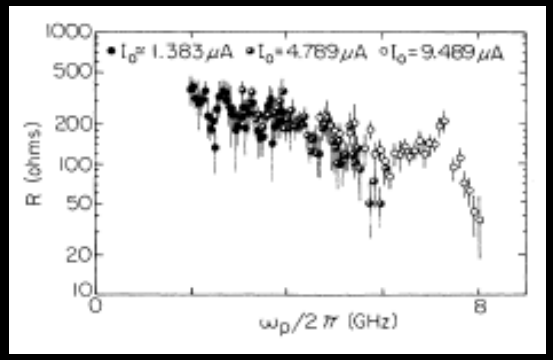
Measurements of Macroscopic Quantum Tunneling out of the Zero-Voltage State of a Current-Biased Josephson Junction

Michel H. Devoret,[a] John M. Martinis, and John Clarke







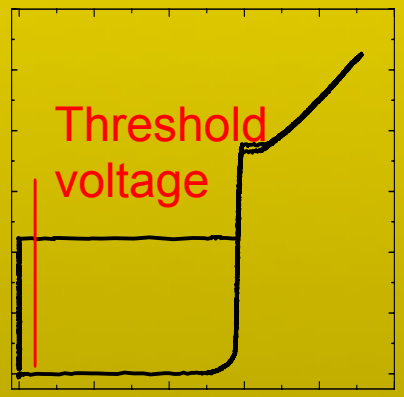


Dilution cryostat

T=1.5 K:
RC filters

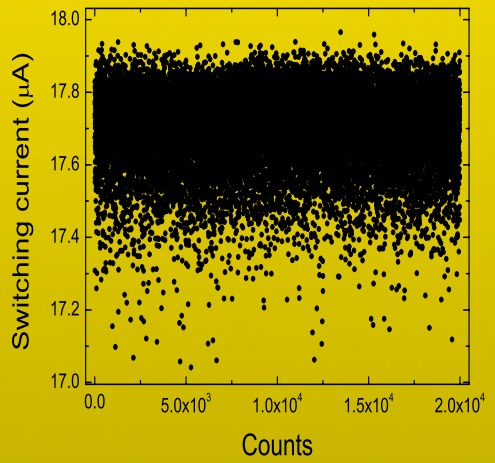
T=50 mK:
Cu powder
filters

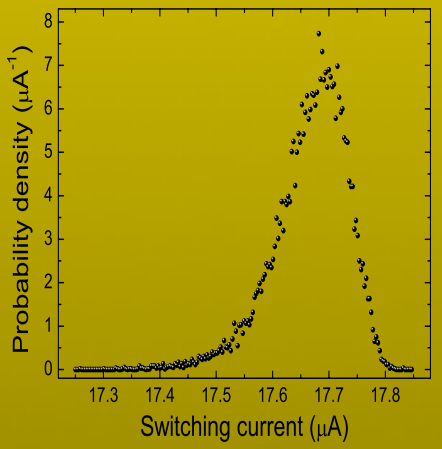
T=20 mK:
sample
stage

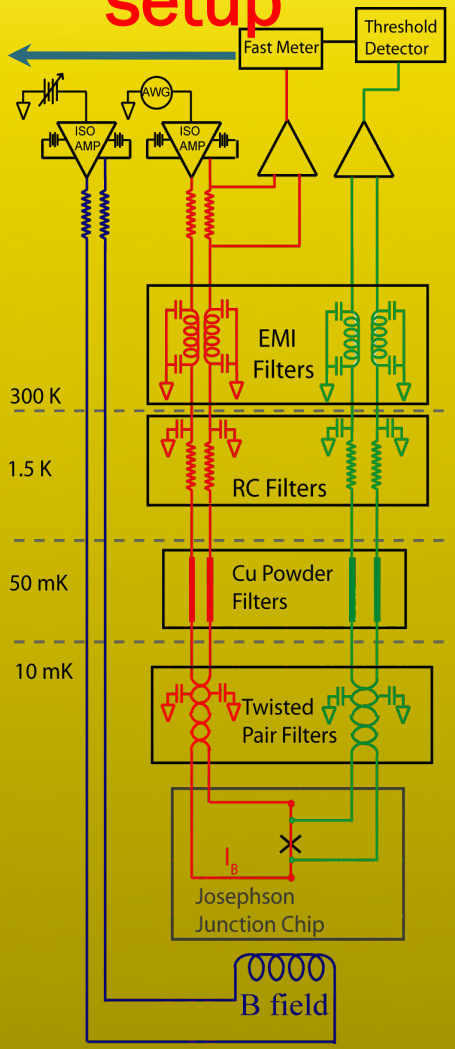


Measurement setup

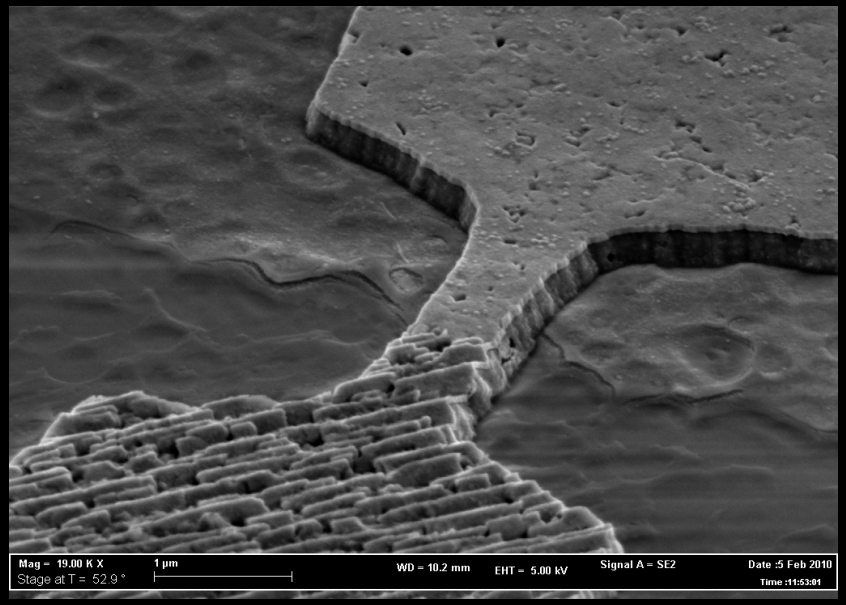
GPIB -> PC

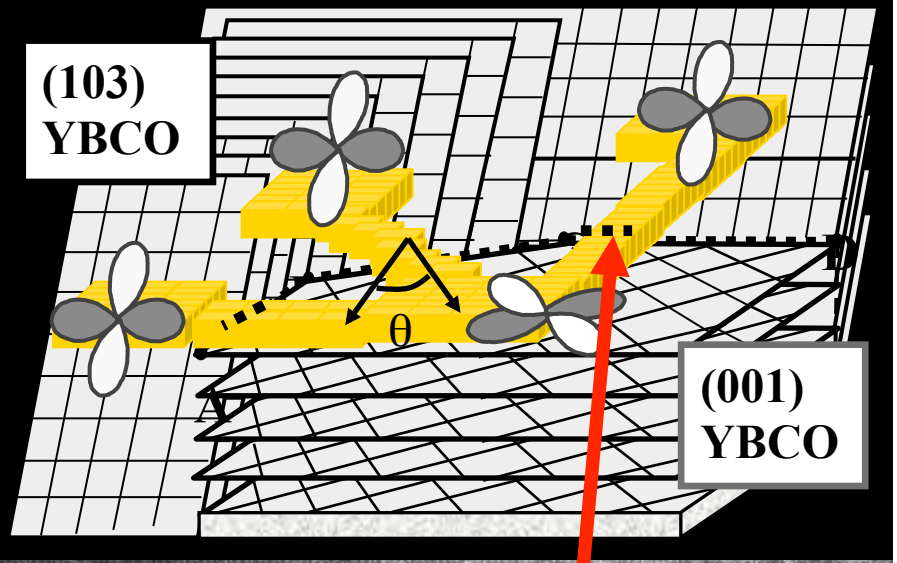


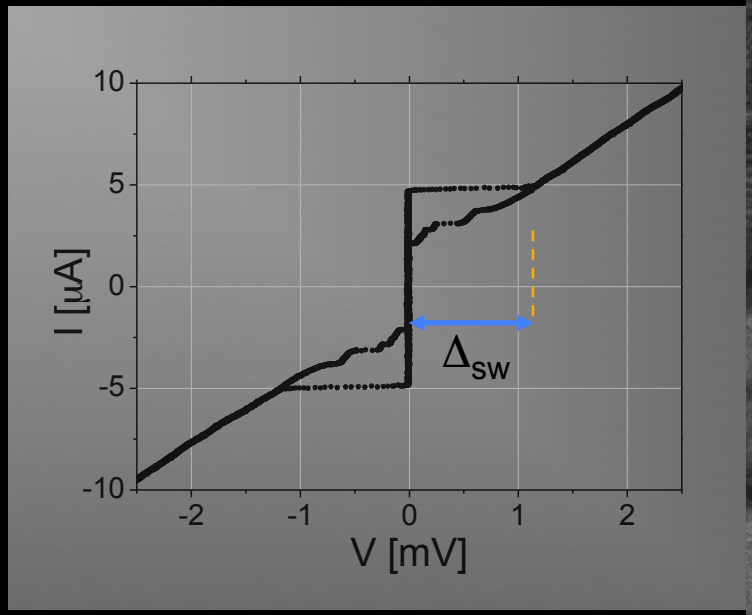


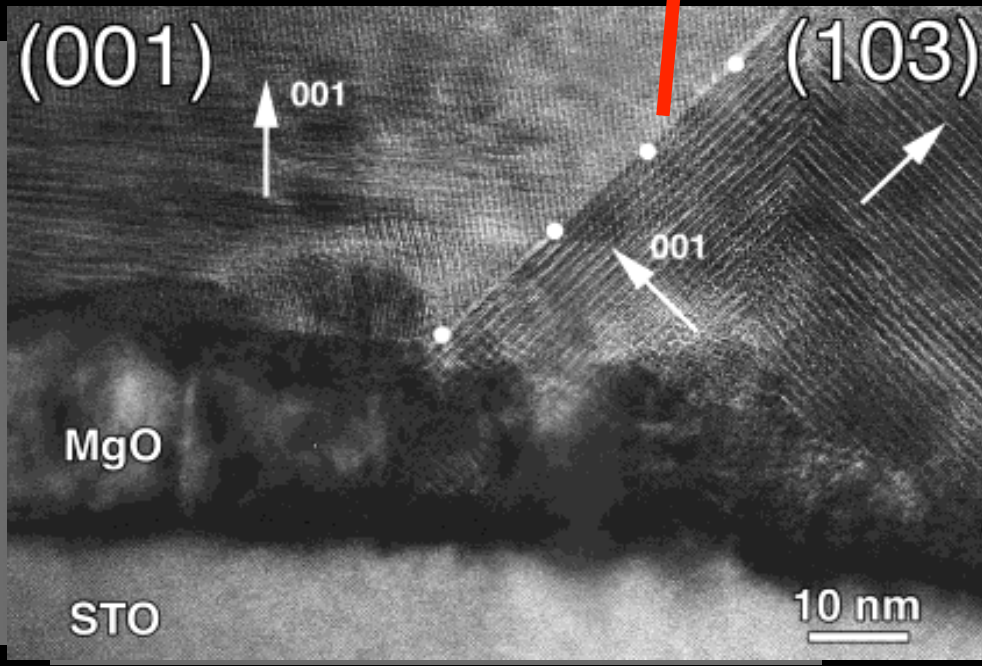


YBCO submicron JJs





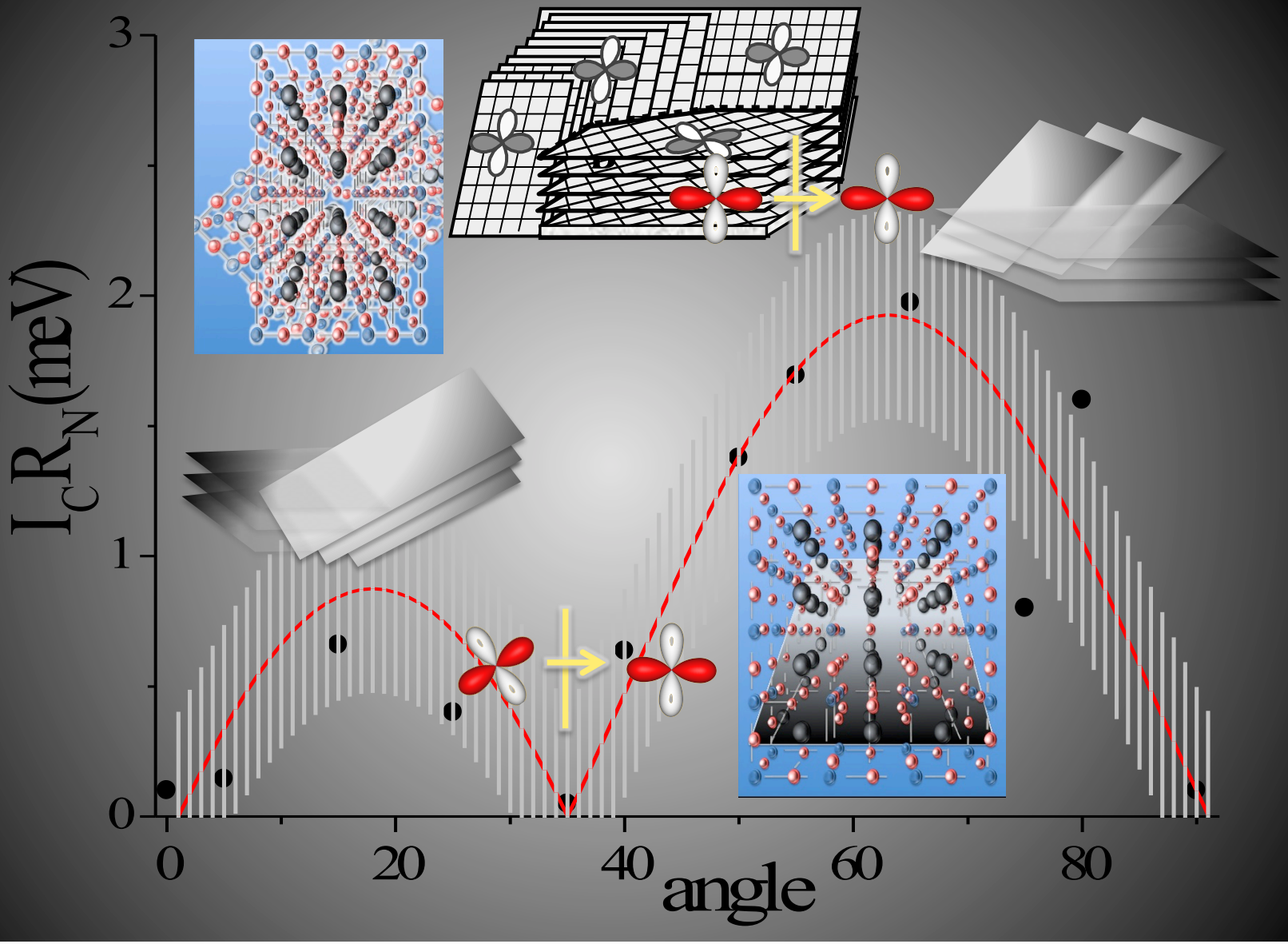




VOLUME 89, NUMBER 20 PHYSICAL REVIEW LETTERS 11 NOVEMBER 2002

Intrinsic *d*-Wave Effects in $YBa_2Cu_3O_{7-\delta}$ Grain Boundary Josephson Junctions

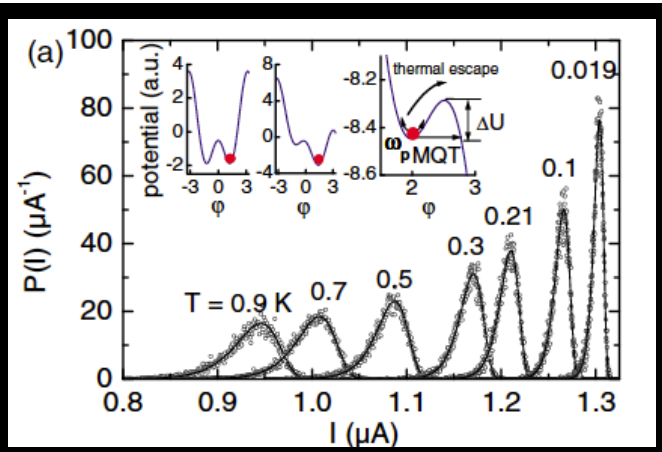
F. Lombardi,[1] F. Tafuri,[2,3] F. Ricci,[1] F. Miletto Granozio,[1] A. Barone,[1] G. Testa,[4] E. Sarnelli,[4]
J. R. Kirtley,[3] and C. C. Tsuei[3]

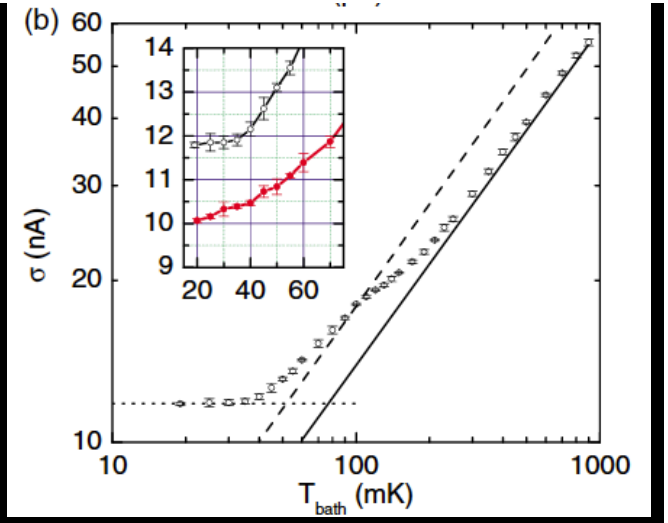


PRL 94, 087003 (2005) PHYSICAL REVIEW LETTERS week ending 4 MARCH 2005

Macroscopic Quantum Tunneling in *d*-Wave $YBa_2Cu_3O_{7-\delta}$ Josephson Junctions

T. Bauch,[1] F. Lombardi,[1] F. Tafuri,[2] A. Barone,[3] G. Rotoli,[4] P. Delsing,[1] and T. Claeson[1]

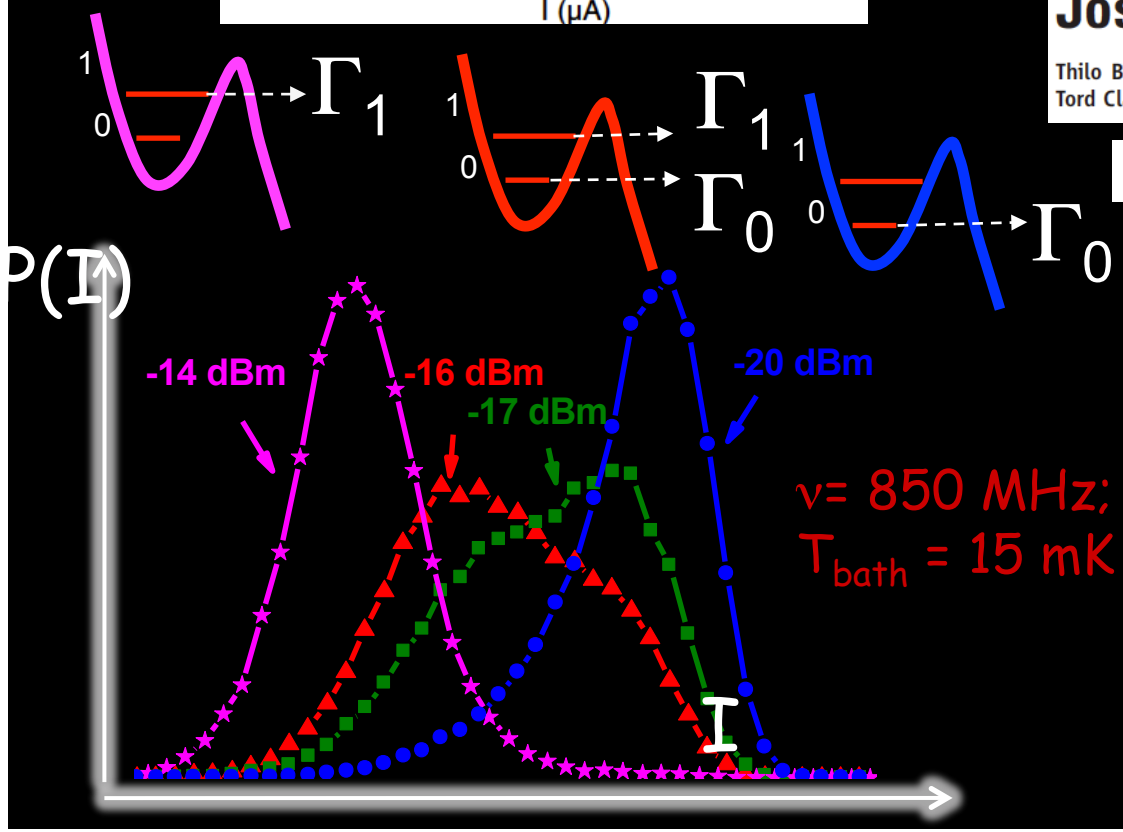


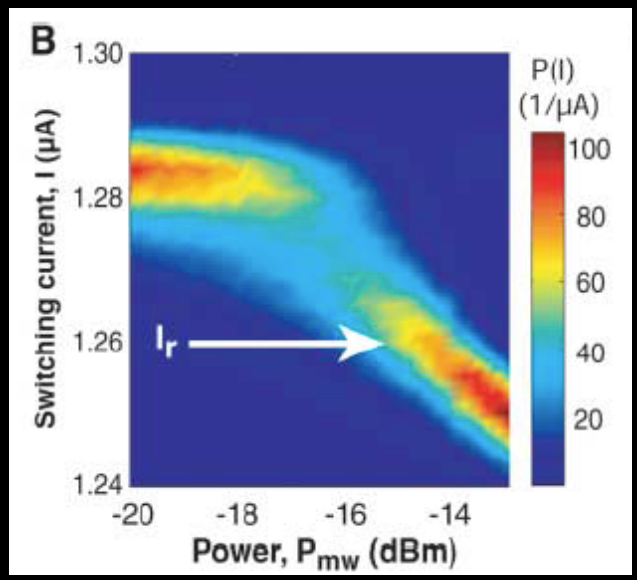


Quantum Dynamics of a d-Wave Josephson Junction

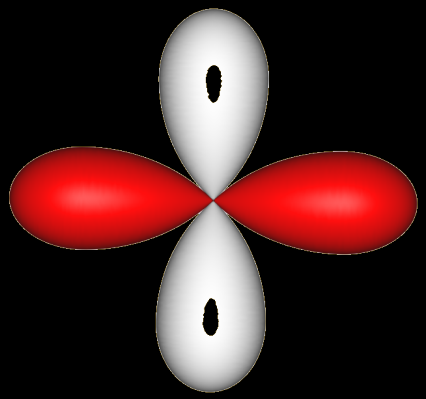
Thilo Bauch,[1] Tobias Lindström,[1] Francesco Tafuri,[2] Giacomo Rotoli,[3] Per Delsing,[1] Tord Claeson,[1] Floriana Lombardi[1]*

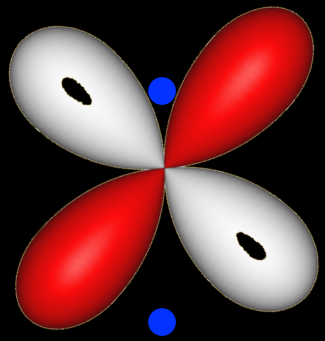
SCIENCE VOL 311 6 JANUARY 2006

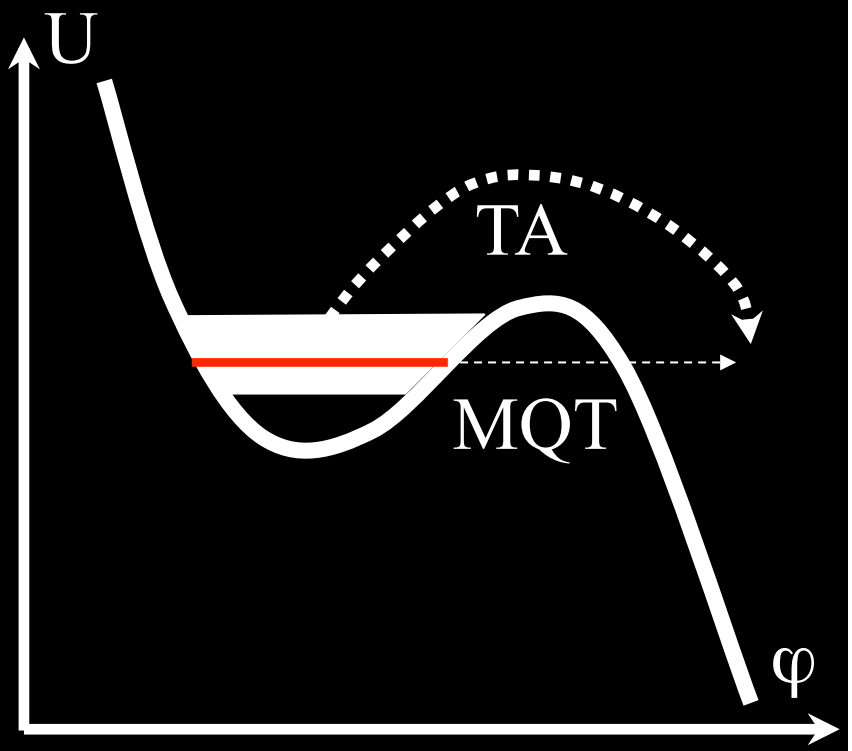




Dissipation in a possible cartoon







High damping

Low to moderate damping

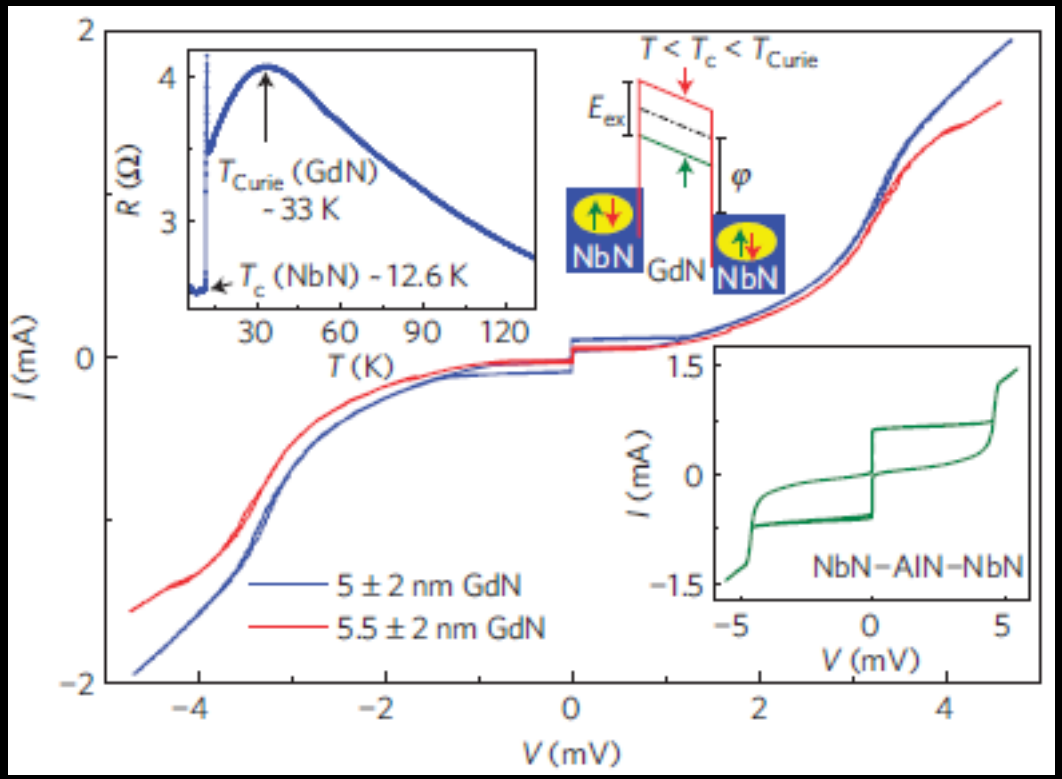
nature materials

LETTERS

PUBLISHED ONLINE: 11 SEPTEMBER 2011 | DOI: 10.1038/NMAT3116

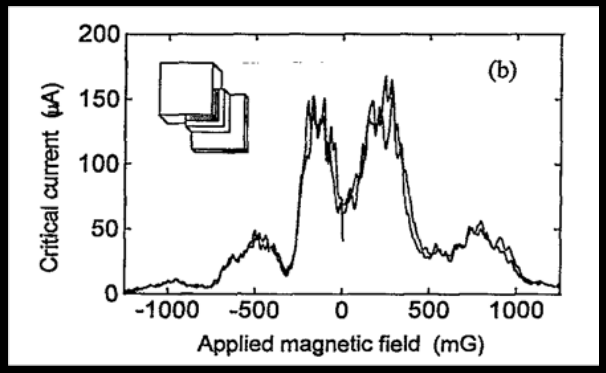
Spin-filter Josephson junctions

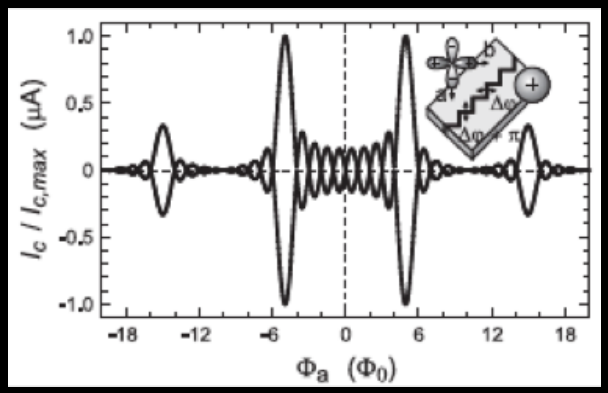
Kartik Senapati*†, Mark G. Blamire and Zoe H. Barber

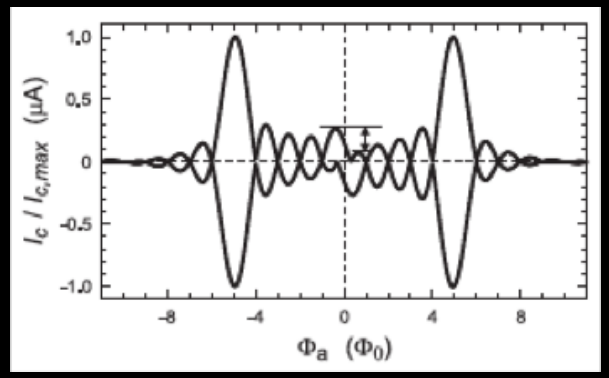


Most common anomalies in Ic(H) geometry

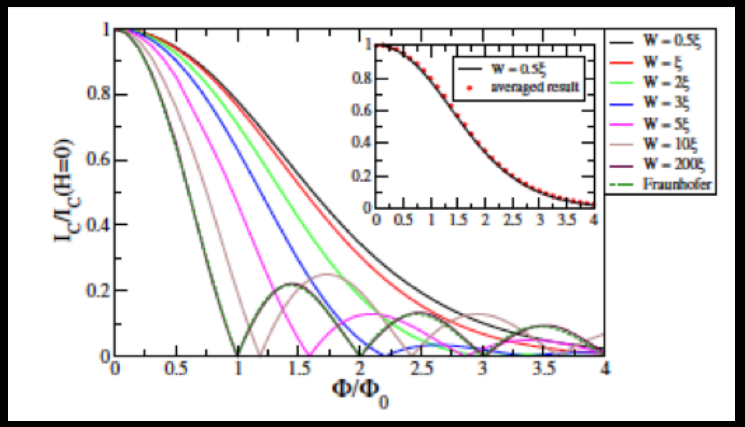
d-wave







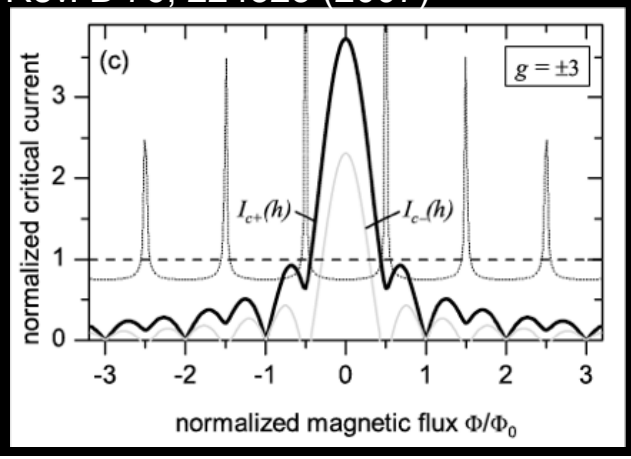
D.J. Van Harlingen, Rev. Mod. Phys. 67, 515 (1995)
H. Smilde et al Phys. Rev. Lett. 88, 57004 (2002)
F. Tafuri and J. Kirtley, Rep. Prog. Phys 68, 2573 (2005)



F.S. Bergeret and J.C.Cuevas, Journal of Low Temperature Physics 153, 304-324 (2008)

2nd harmonic

E. Goldobin, D. Koelle, R. Kleiner and A. Buzdin, Phys. Rev. B 76, 224523 (2007)



Macroscopic quantum tunneling in a SFS JJ

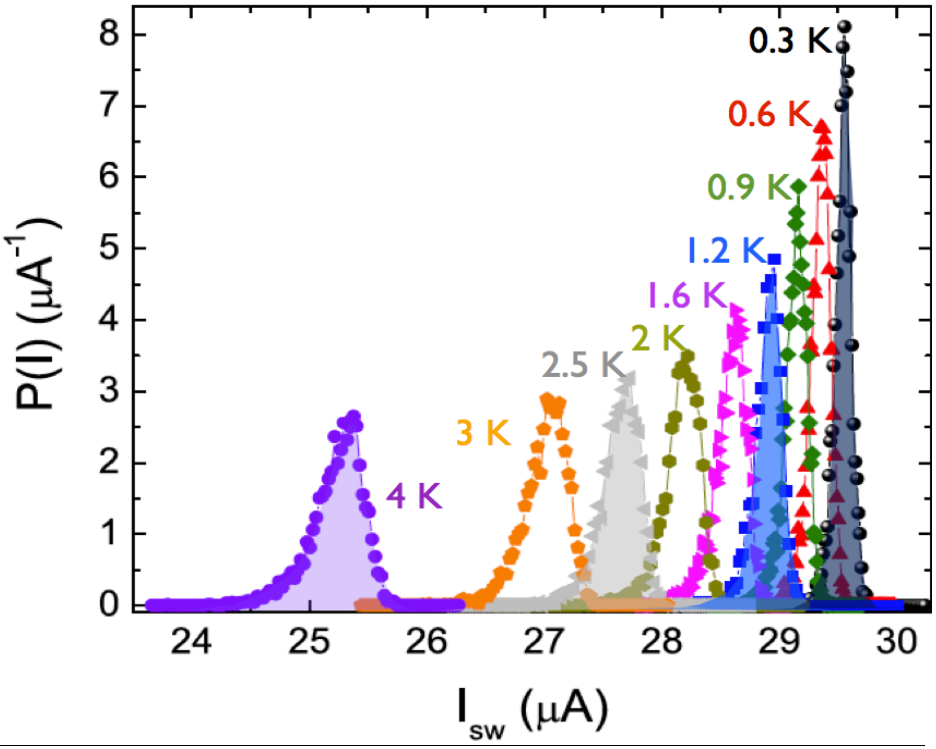
Received 12 Dec 2014 | Accepted 1 May 2015 | Published 9 Jun 2015

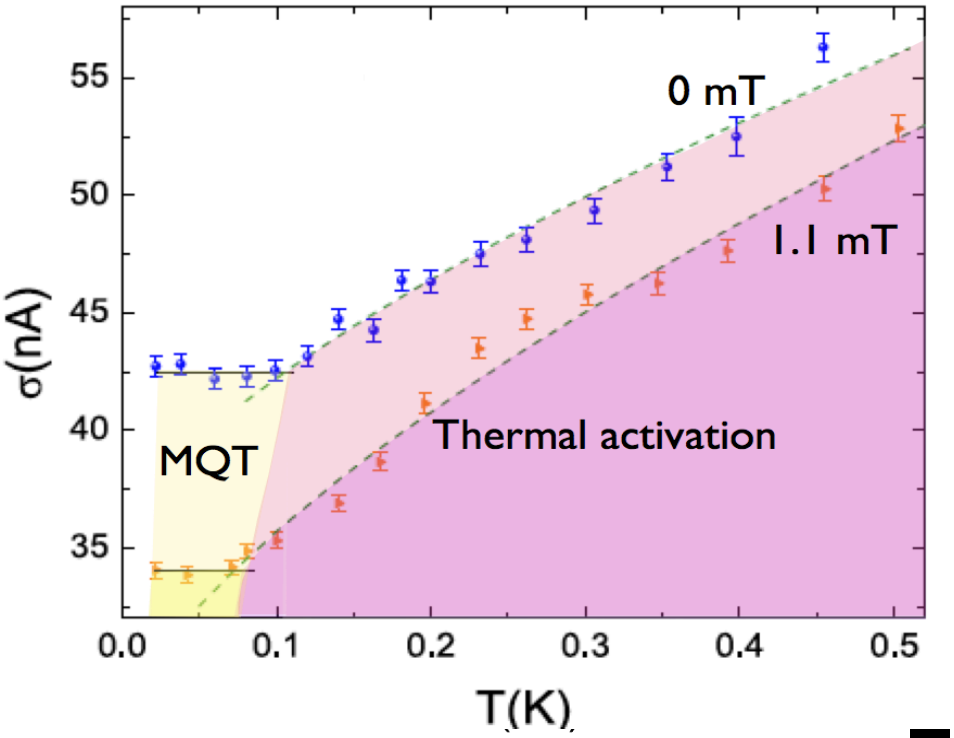
DOI: 10.1038/ncomms8376 OPEN

Macroscopic quantum tunnelling in spin filter ferromagnetic Josephson junctions

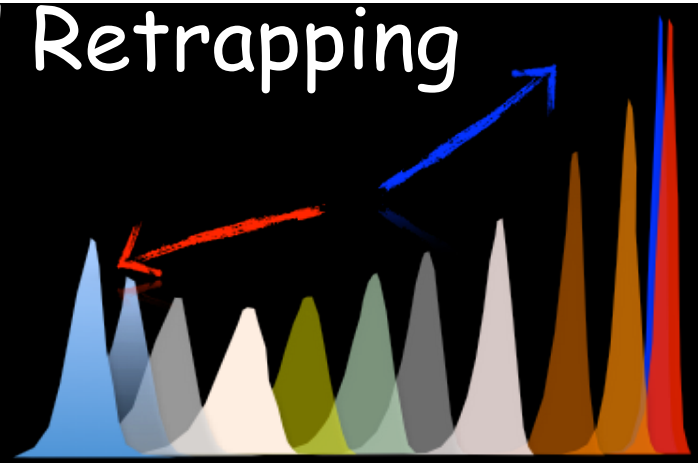
D. Massarotti[1,2], A. Pal[3], G. Rotoli[4], L. Longobardi[4,5], M.G. Blamire[3] & F. Tafuri[2,4]

nature COMMUNICATIONS





Multiple Escape and Retrapping

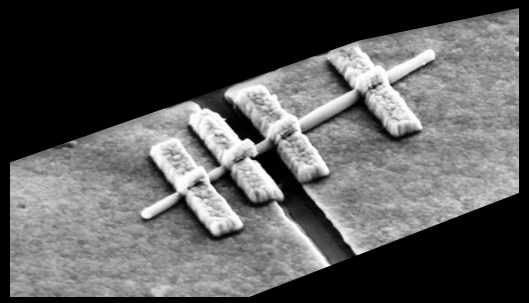


TA

MQT

PD

Running State



Moderately damped JJs (1<Q<5)

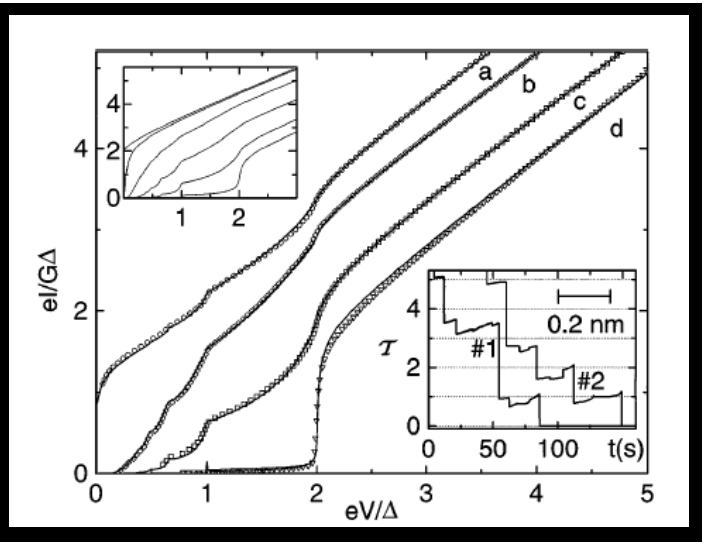
Iansiti, Tinkham et al. PRB 39 (1989)
Kautz & Martinis, PRB 42 (1990)
Vion,Joyez, Esteve, Devoret PRL 77(1996)
Kivioja, Pekola et al. PRL 94 (2005)
Mannik, Lukens et al. PRB 71 (2005)
Krasnov et al. PRB 76 (2007)
Krasnov, Bauch et al. PRL 95 (2005)
Longobardi et al. PRB 84 (2011); PRL 109 (2012)

In a 'nano-world', reduction of I_c unavoidably leads to a reduction of Q (increase in dissipation) and of the ratio $E_J/E_C=(I_C\Phi_O/2\pi)/(e^2/C)$

VOLUME 78, NUMBER 18 PHYSICAL REVIEW LETTERS 5 MAY 1997

Conduction Channel Transmissions of Atomic-Size Aluminum Contacts

E. Scheer, P. Joyez, D. Esteve, C. Urbina,* 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 4 February 1997)



VOLUME 85, NUMBER 1 PHYSICAL REVIEW LETTERS 3 JULY 2000

Supercurrent in Atomic Point Contacts and Andreev States

M. F. Goffman,[1] R. Cron,[1] A. Levy Yeyati,[2] P. Joyez,[1] M. H. Devoret,[1] D. Esteve,[1] and C. Urbina[1]
[1]*Service de Physique de l'Etat Condensé, CEA-Saclay, F-91191 Gif-sur-Yvette Cedex, France*

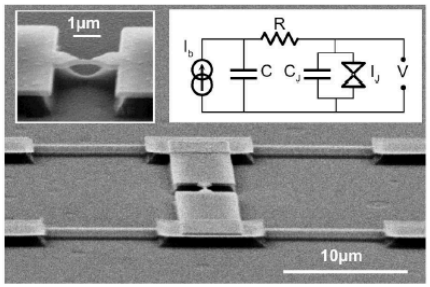


FIG. 2. Micrograph of Al microbridge in a dissipative environment. Each *IV* probe contains a AuCu (weight ratio 3:1) resistor (10 μm-long, 500 nm wide, and 30 or 50 nm thick) and a large (2.5 mm)^2, 180 nm thick AuCu/Al pad (not shown) that forms with the metallic substrate a large capacitor. Substrate is phosphor-bronze covered by a 2 μm thick layer of polyimide. Left inset: side view of bridge (150 nm thick Al layer with 100 nm wide constriction in the middle) suspended by selective etching of polyimide. Bridge is broken by controlled hard

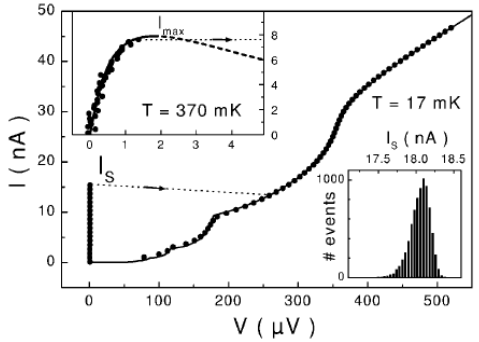
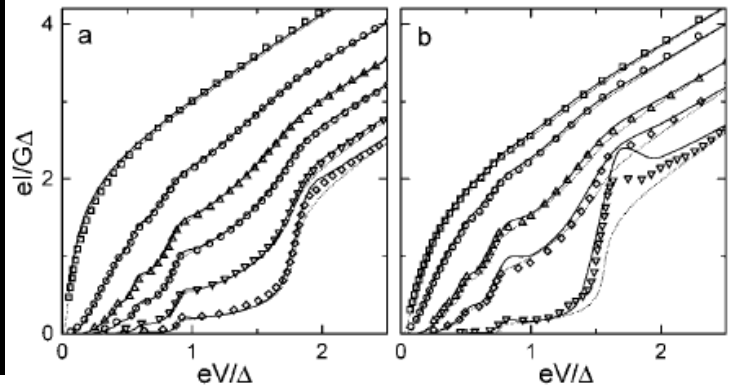


FIG. 3. Large scale *IV* characteristic of atomic contact, measured at 17 mK (dots). Switching at current I_s from super-



VOLUME 86, NUMBER 2 PHYSICAL REVIEW LETTERS 8 JANUARY 2001

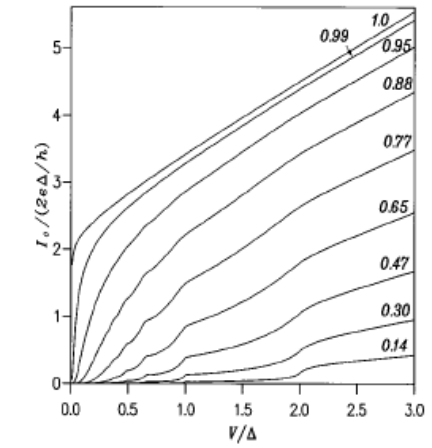
Proximity Effect and Multiple Andreev Reflections in Gold Atomic Contacts

E. Scheer,[1,*] W. Belzig,[2] Y. Naveh,[3,†] M. H. Devoret,[4] D. Esteve,[4] and C. Urbina[4]

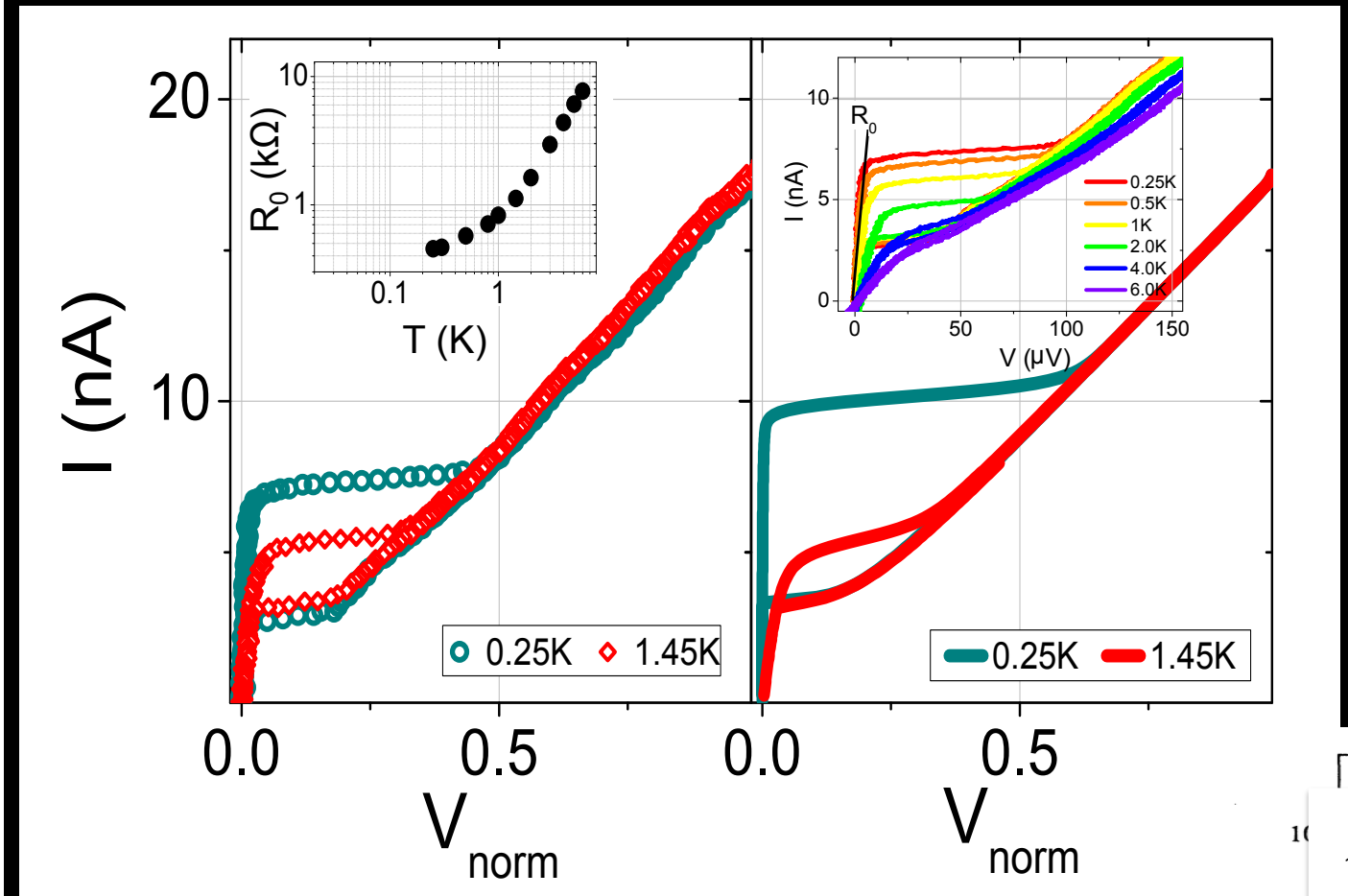
PHYSICAL REVIEW B VOLUME 54, NUMBER 10 1 SEPTEMBER 1996-II

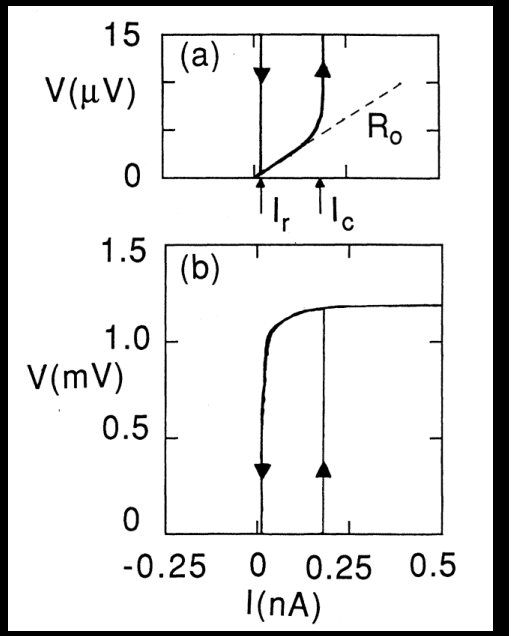
Hamiltonian approach to the transport properties of superconducting quantum point contacts

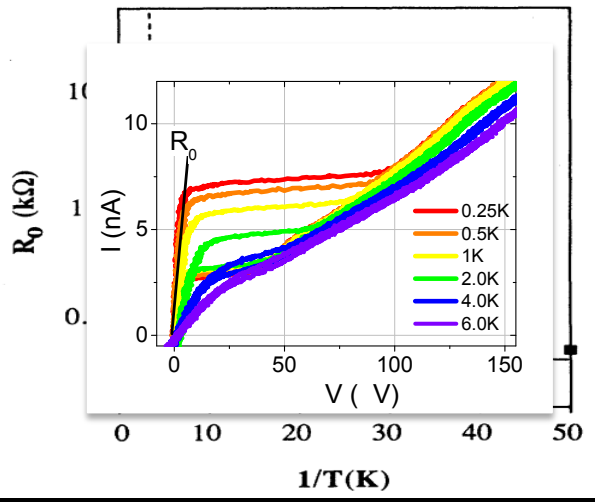
J. C. Cuevas, A. Martín-Rodero, and A. Levy Yeyati
Departamento de Física Teórica de la Materia Condensada C-V, Facultad de Ciencias, Universidad Autónoma de Madrid,



Phase dynamics in the 'very' low Jc limit







D. Stornaiuolo, G. Rotoli, D. Massarotti, F. Carillo, L. Longobardi, F. Beltram and F. Tafuri Phys. Rev. B(2013)

Phase dynamics in the 'very' low Jc limit

PHYSICAL REVIEW B VOLUME 39, NUMBER 10 1 APRIL 1989

Charging effects and quantum properties of small superconducting tunnel junctions

M. Iansiti, M. Tinkham, A. T. Johnson, Walter F. Smith, and C. J. Lobb

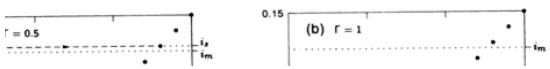
$\varphi \longrightarrow E_J = I_c\phi_0/2\pi$ $\quad$ N $\longrightarrow E_C = e^2/2C$

$$H = E_C\left(Q/e^2\right) - E_J\cos\varphi \quad [\varphi,Q] = i2e \quad \delta\varphi \cong \left(\frac{E_C}{E_J}\right)^{1/4}$$

VIEW B VOLUME 42, NUMBER 16 1 DECEMBER 1990

Noise-affected *I-V* curves in small hysteretic Josephson junctions

R. L. Kautz and John M. Martinis
National Institute of Standards and Technology, 325 Broadway, Boulder, Colorado 80303-3328
(Received 11 June 1990)



Phase dynamics in the 'very' low Jc limit

PHYSICAL REVIEW B VOLUME 42, NUMBER 16 1 DECEMBER 1990

Noise-affected *I-V* curves in small hysteretic Josephson junctions

R. L. Kautz and John M. Martinis
National Institute of Standards and Technology, 325 Broadway, Boulder, Colorado 80303-3328
(Received 11 June 1990)

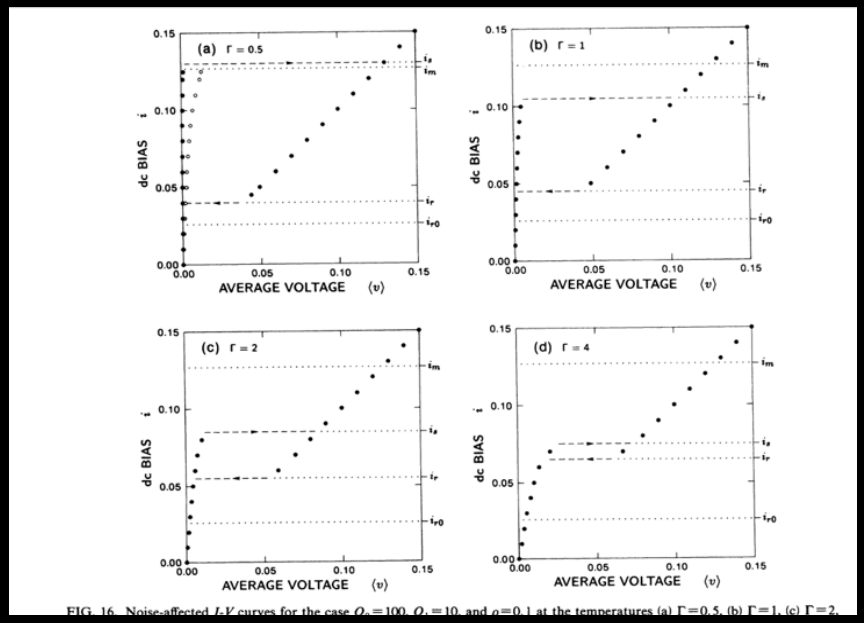
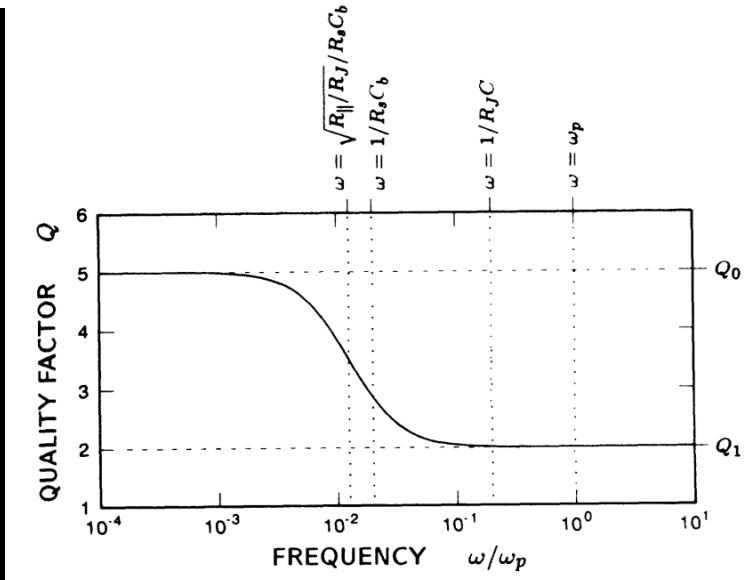


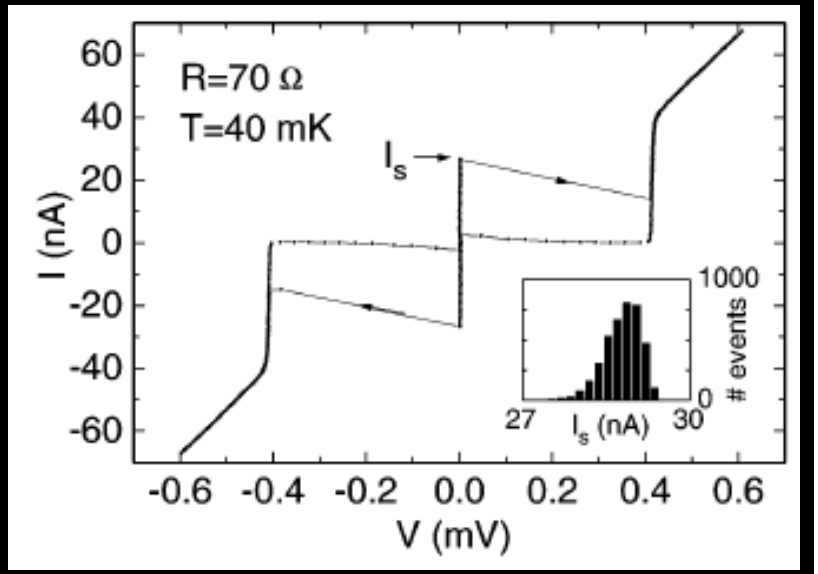
FIG. 16. Noise-affected *I-V* curves for the case $Q_0 = 100$, $Q_1 = 10$, and $\alpha = 0.1$ at the temperatures (a) $\Gamma = 0.5$, (b) $\Gamma = 1$, (c) $\Gamma = 2$,

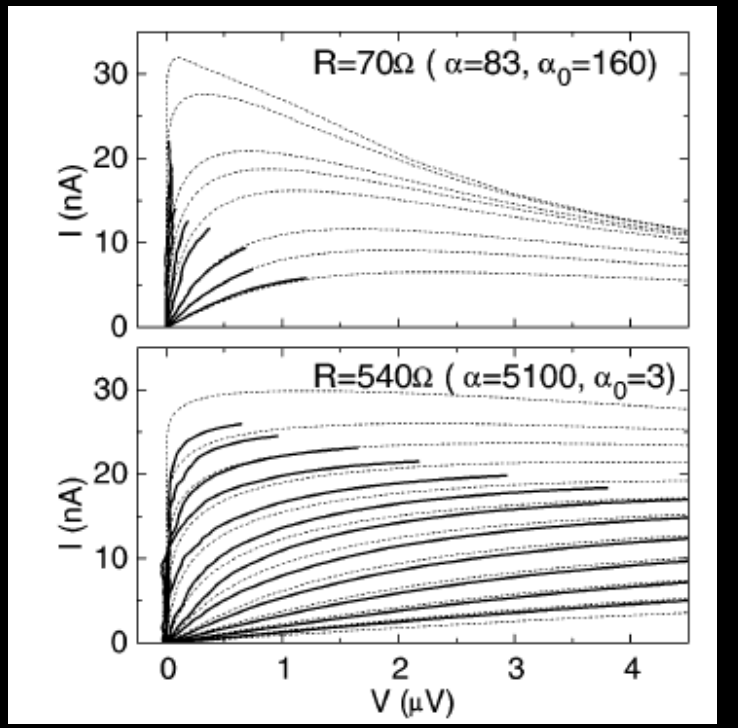


VOLUME 77, NUMBER 16 PHYSICAL REVIEW LETTERS 14 OCTOBER 1996

Thermal Activation above a Dissipation Barrier: Switching of a Small Josephson Junction

D. Vion,[1] M. Götz,[1,2] P. Joyez,[1] D. Esteve,[1] and M. H. Devoret[1]
[1]*Service de Physique de l'Etat Condensé, CEA-Saclay, F-91191 Gif-sur-Yvette, France*
[2]*Institut für Festkörperphysik, Friedrich-Schiller-Universität, D-07743 Jena, Germany*
(Received 28 June 1996)

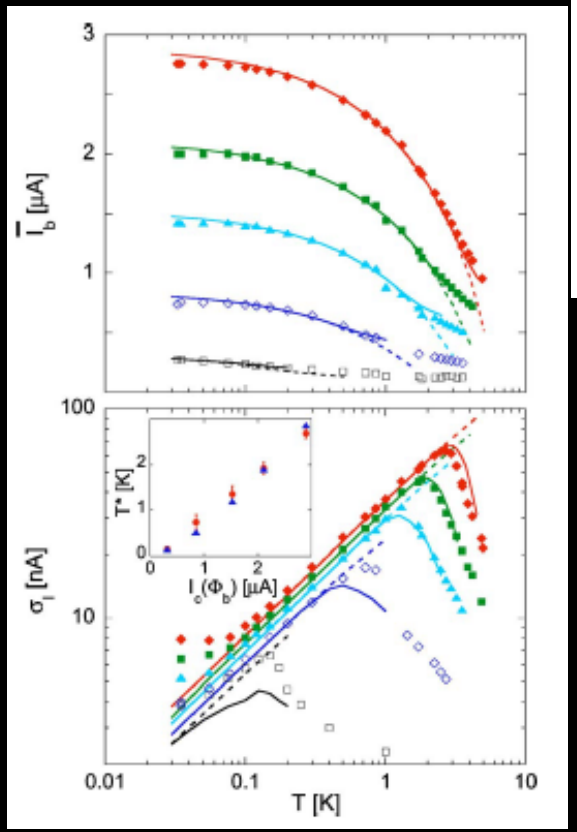


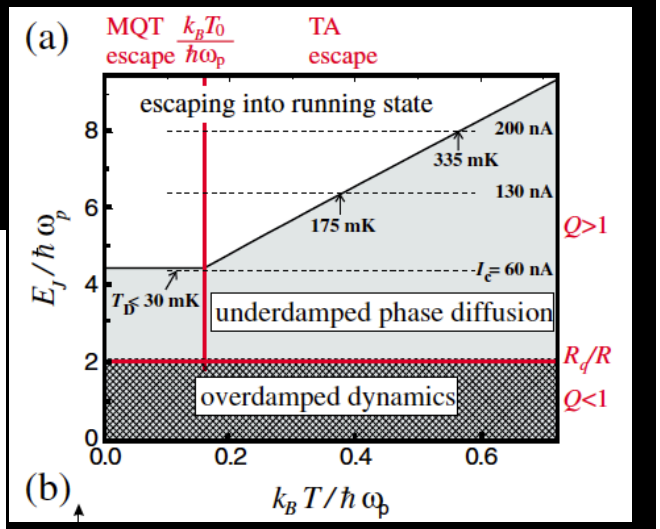


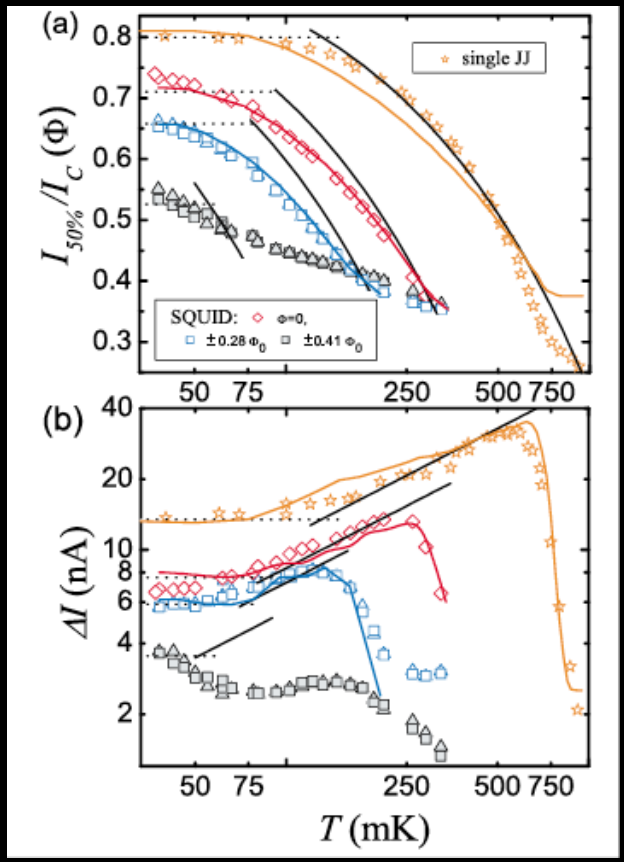
PRL 94, 247002 (2005) PHYSICAL REVIEW LETTERS 24 JUNE 2005

Observation of Transition from Escape Dynamics to Underdamped Phase Diffusion in a Josephson Junction

J. M. Kivioja,[1] T. E. Nieminen,[1] J. Claudon,[2] O. Buisson,[2] F. W. J. Hekking,[3] and J. P. Pekola[1]







PHYSICAL REVIEW B 71, 220509(R) (2005)

Crossover from Kramers to phase-diffusion switching in moderately damped Josephson junctions

J. Männik,[1] S. Li,[2] W. Qiu,[2] W. Chen,[1] V. Patel,[1] S. Han,[2] and J. E. Lukens[1]
[1]*Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794, USA*
[2]*Department of Physics and Astronomy, University of Kansas, Lawrence, Kansas 66045, USA*
(Received 1 April 2005; published 24 June 2005)

CHAOS 15, 026106 (2005)

Quantum Brownian motion with large friction

Joachim Ankerhold[a)]
Physikalisches Institut, Albert-Ludwigs-Universität, 79104 Freiburg, Germany
and Service de Physique de l'Etat Condense, Centre d'Etudes de Saclay, 91191 Gif-sur-Yvette, France

Hermann Grabert
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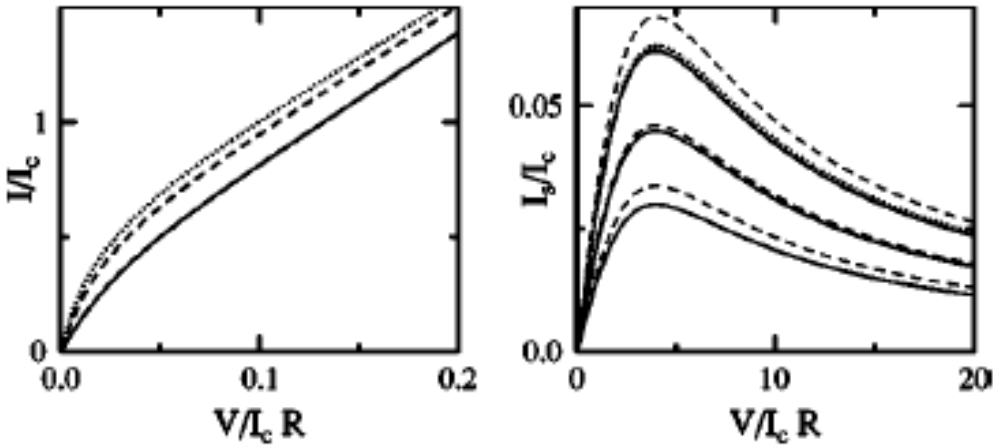
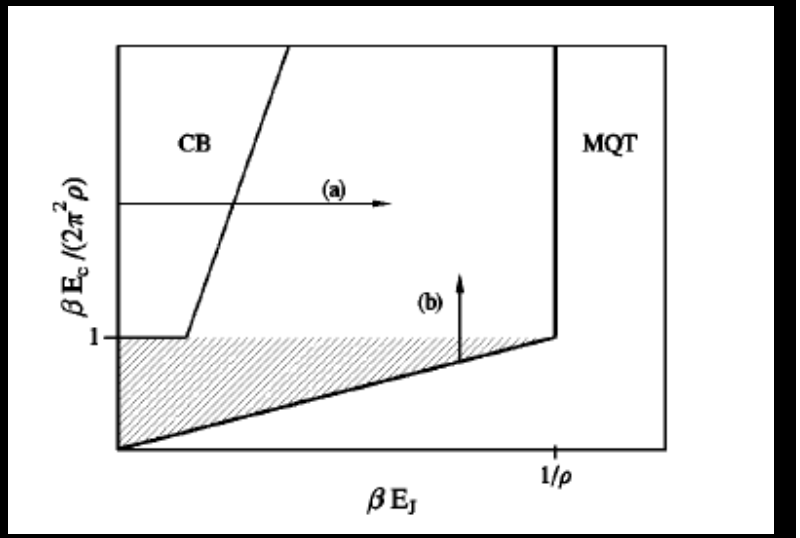




VOLUME 58 30 MARCH 1987 NUMBER 13

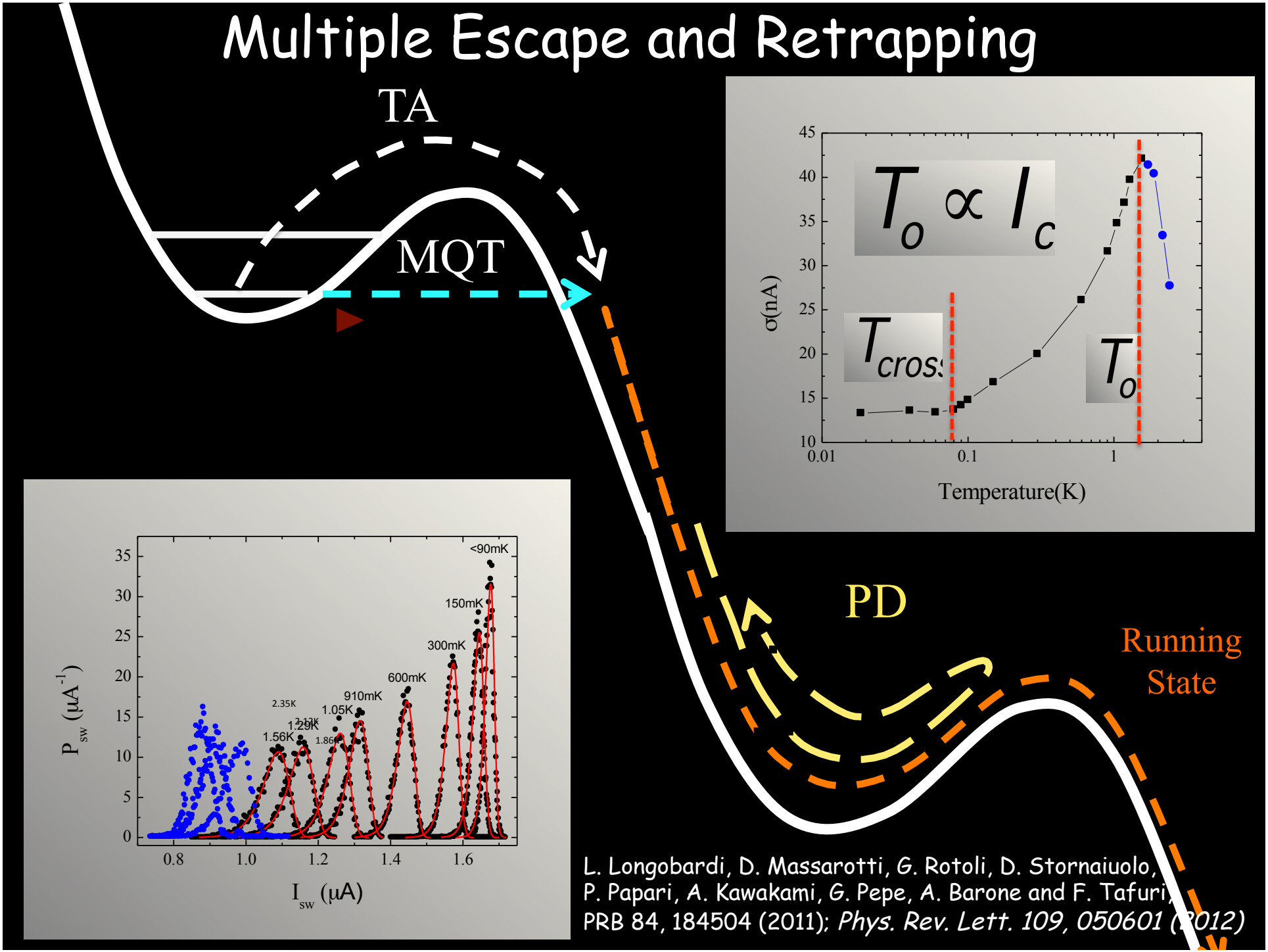
Localization and Anomalous Diffusion of a Damped Quantum Particle

Hermann Grabert
Service de Physique du Solide et de Résonance Magnétique, Centre d'Etudes Nucléaires de Saclay, 91191 Gif-sur-Yvette Cédex, France

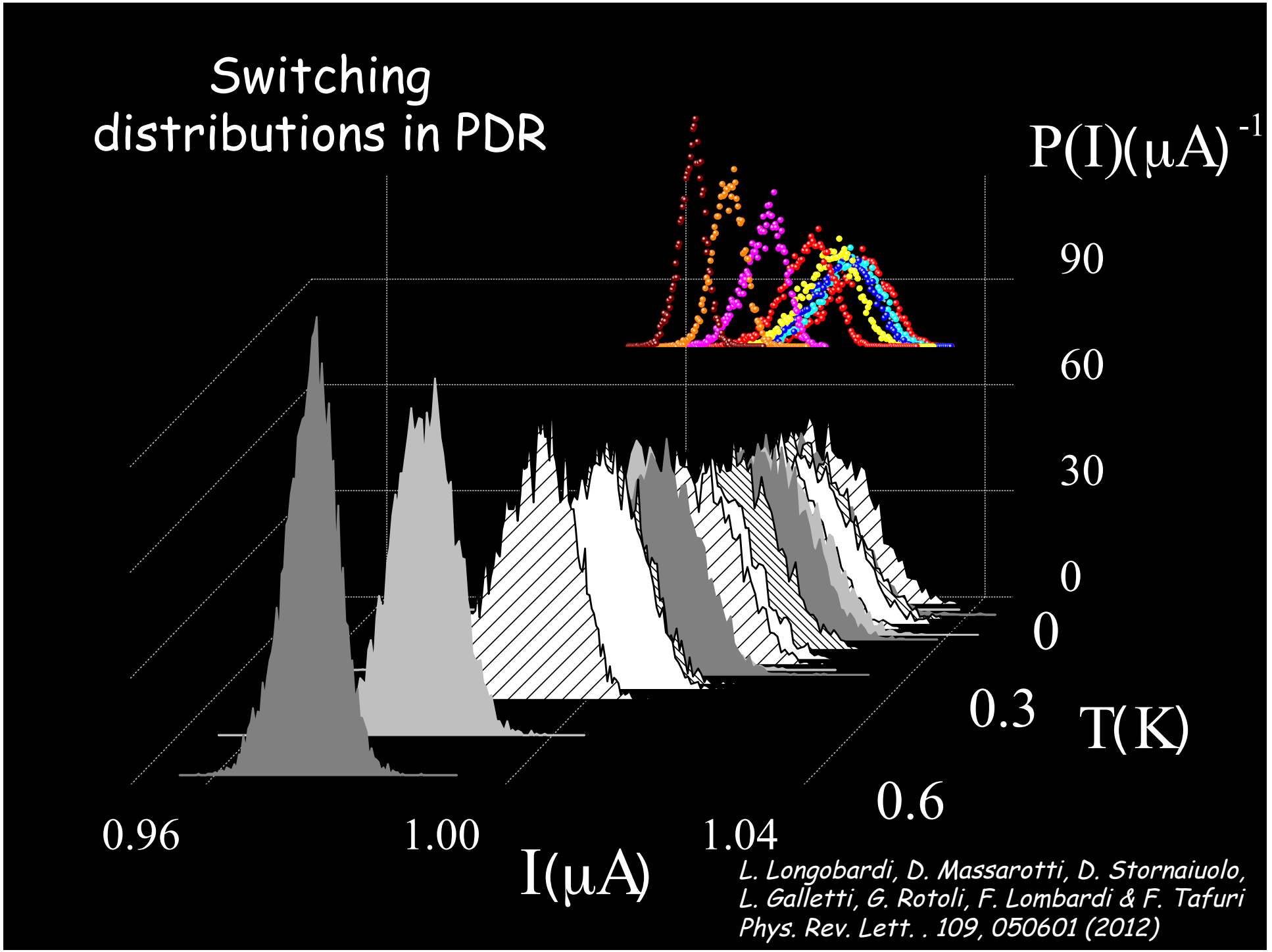
and

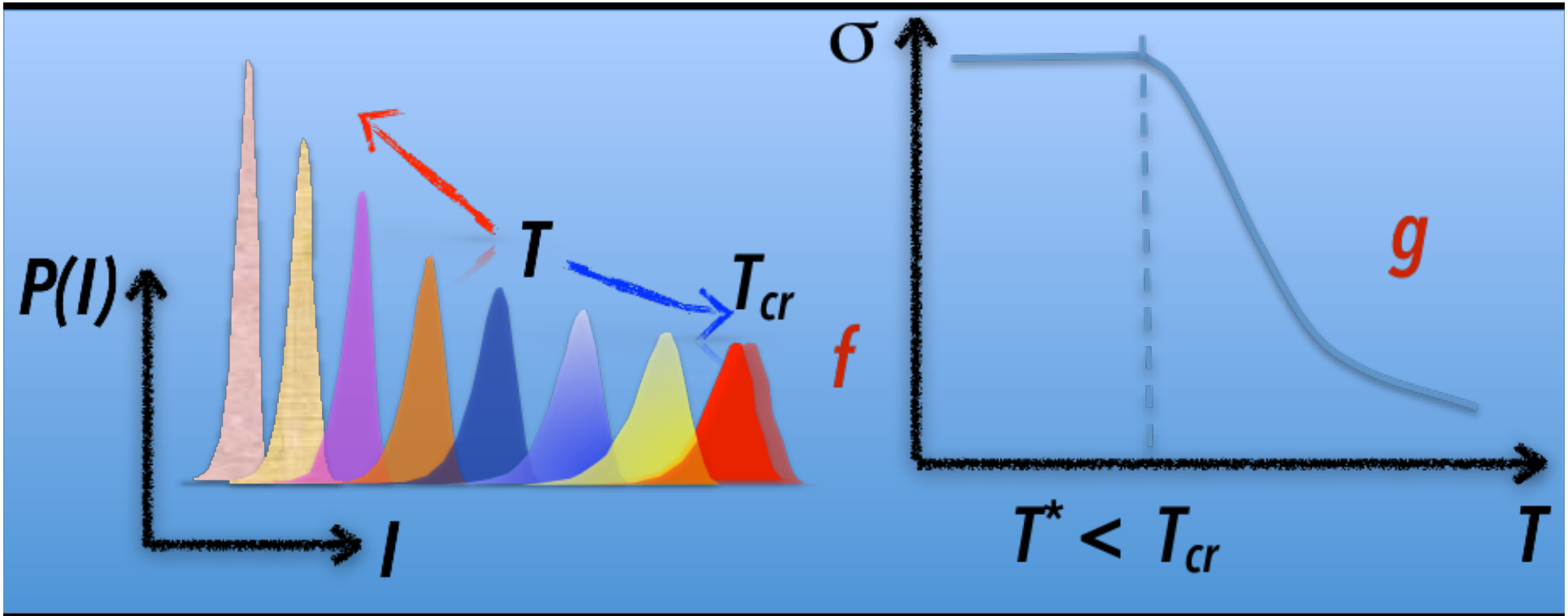
Peter Schramm and Gert-Ludwig Ingold
Institut für Theoretische Physik, Universität Stuttgart, D-7000 Stuttgart 80, Germany
(Received 1 December 1986)

Multiple Escape and Retrapping



L. Longobardi, D. Massarotti, G. Rotoli, D. Stornaiuolo, P. Papari, A. Kawakami, G. Pepe, A. Barone and F. Tafuri, PRB 84, 184504 (2011); *Phys. Rev. Lett. 109, 050601 (2012)*

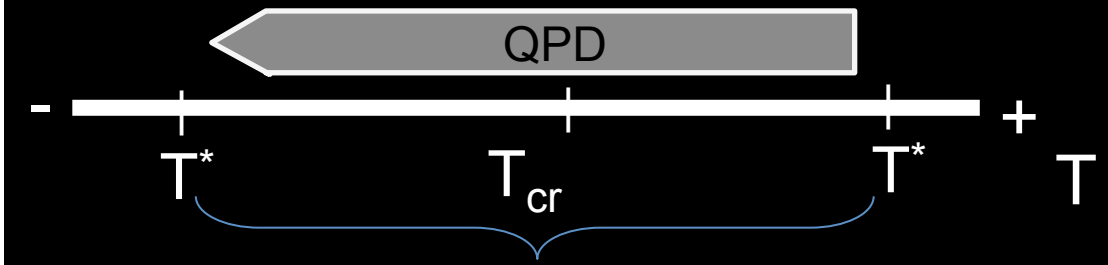

Switching
distributions in PDR
P(I)(μA)-1
90
60
30
0
0
0.3
T(K)
0.6
0.96
1.00
1.04
I(μA)
L. Longobardi, D. Massarotti, D. Stornaiuolo,
L. Galletti, G. Rotoli, F. Lombardi & F. Tafuri
Phys. Rev. Lett. . 109, 050601 (2012)

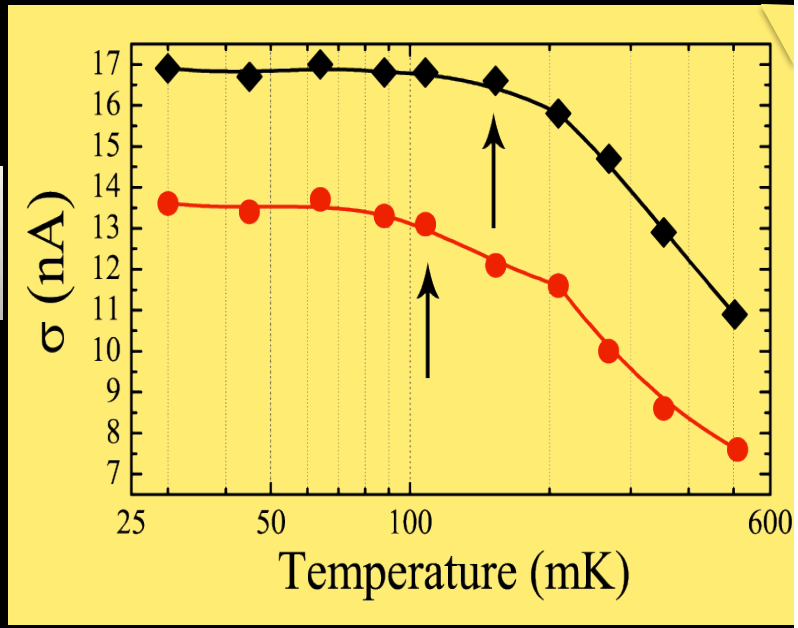


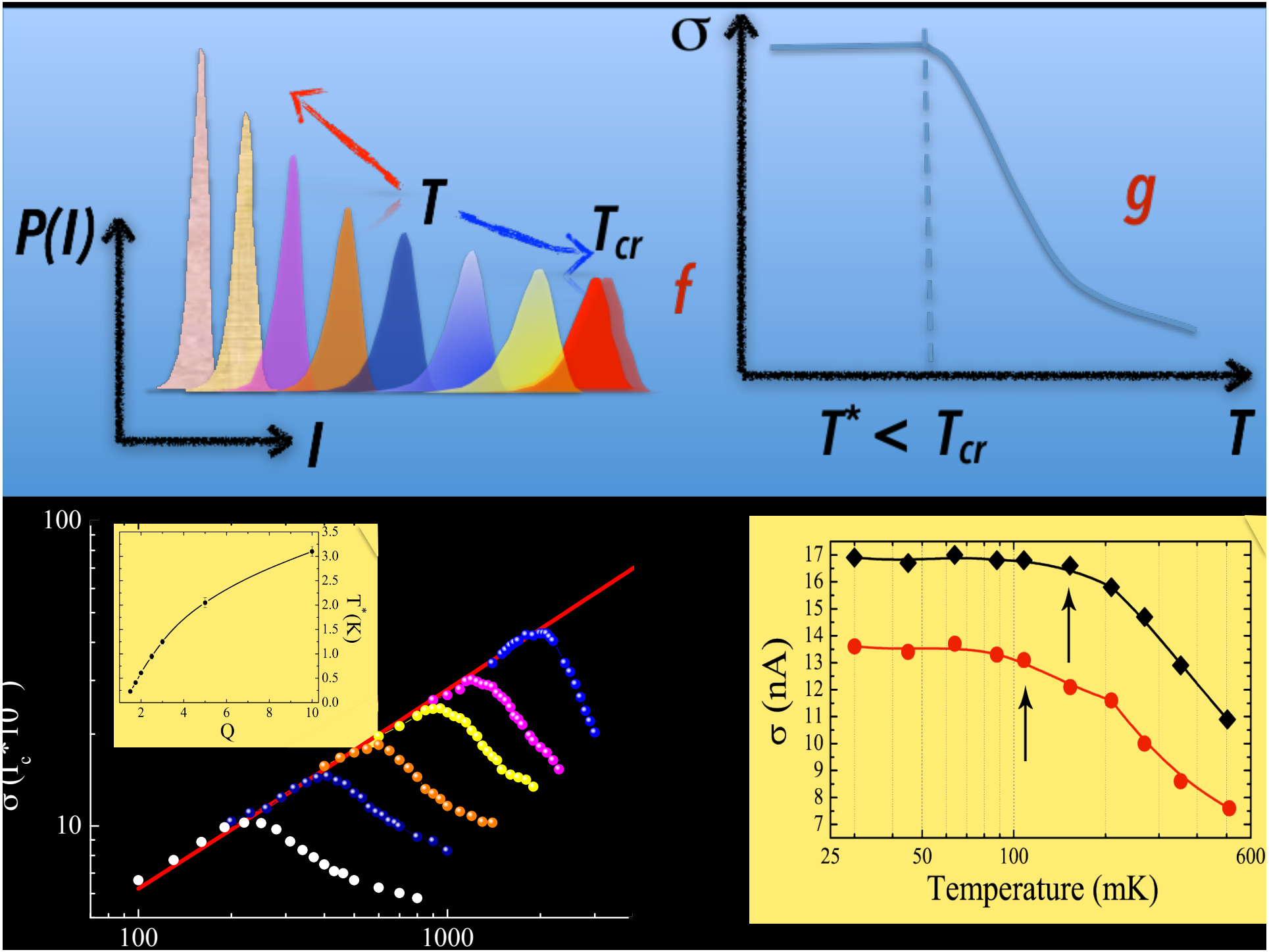
L. Longobardi, D. Massarotti, D. Stornaiuolo, L. Galletti, G. Rotoli, F. Lombardi & F. Tafuri
Phys. Rev. Lett. . 109, 050601 (2012)

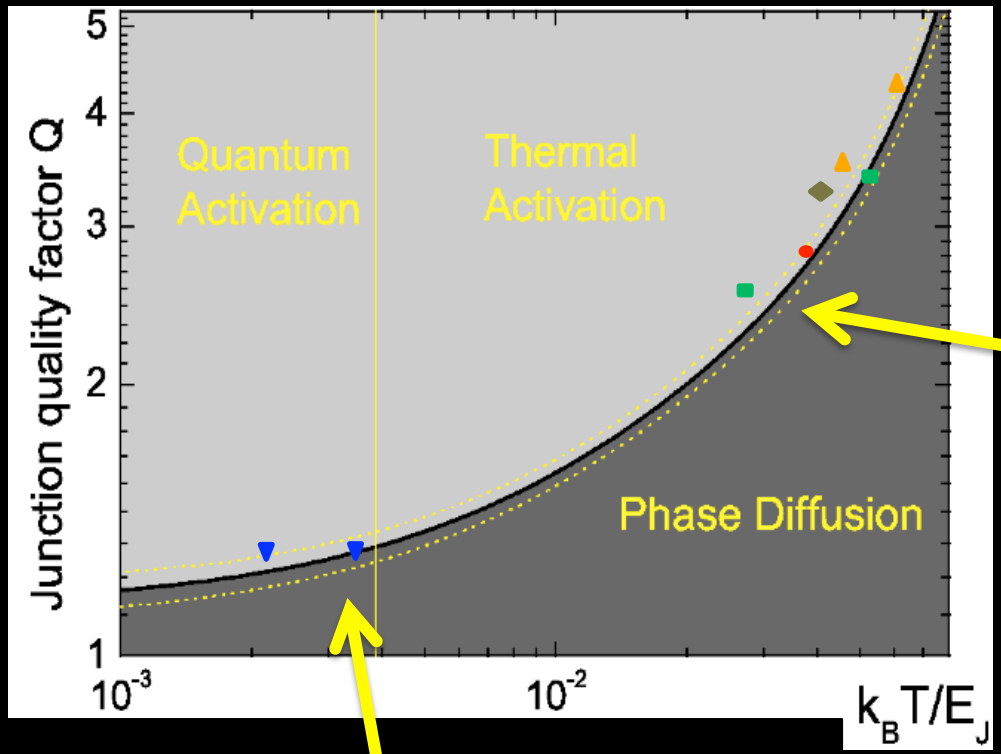
$$T^* \propto I_c$$

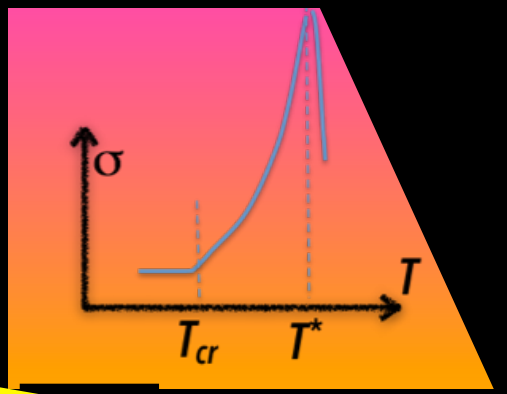
$$T_{cr} \propto \sqrt{I_c / C}$$

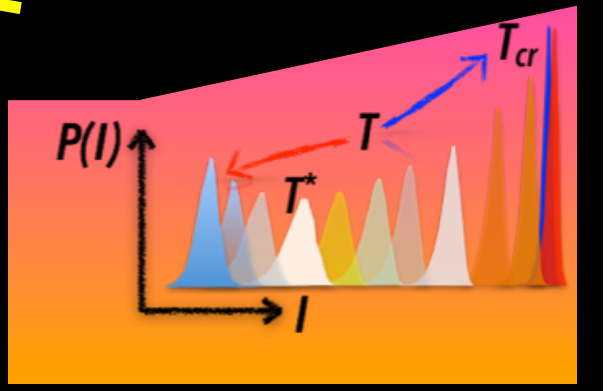


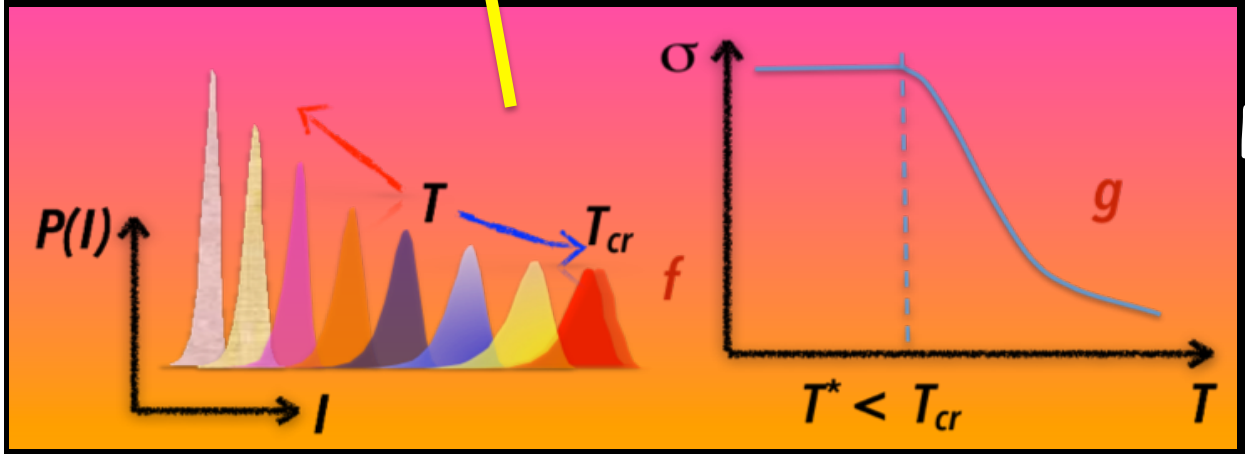



P(I)
I
T
T_{cr}
f
σ
g
$T^* < T_{cr}$
T
100
10
100
1000
Q
T^* (K)
σ (nA)
Temperature (mK)
25
50
100
600



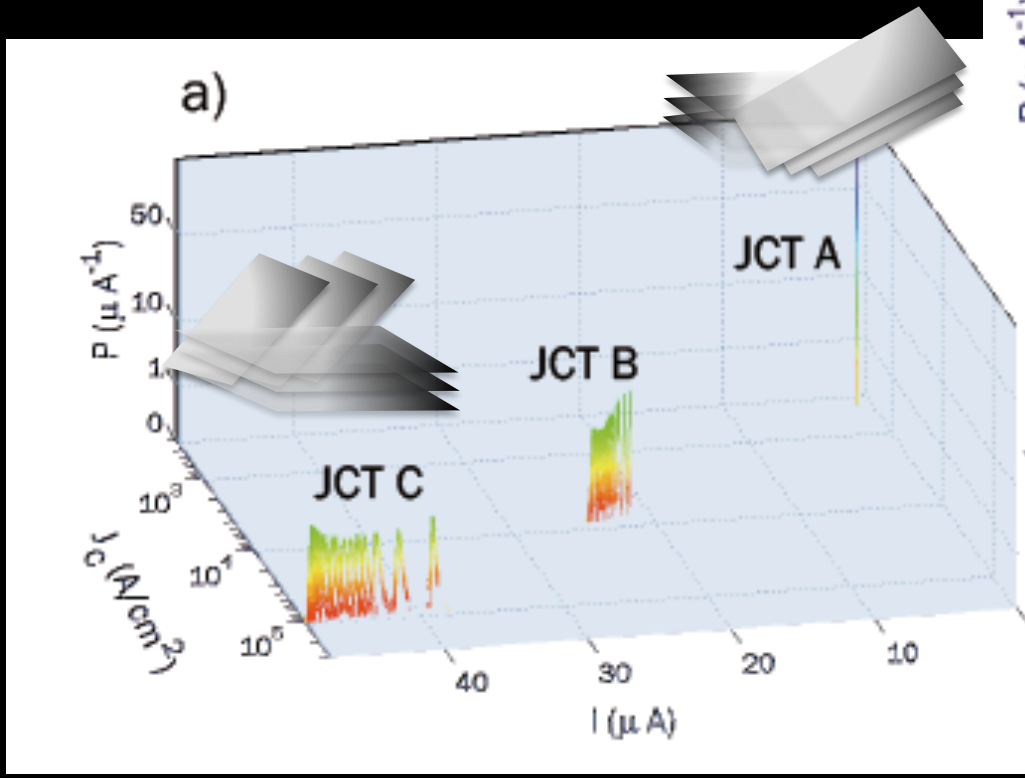


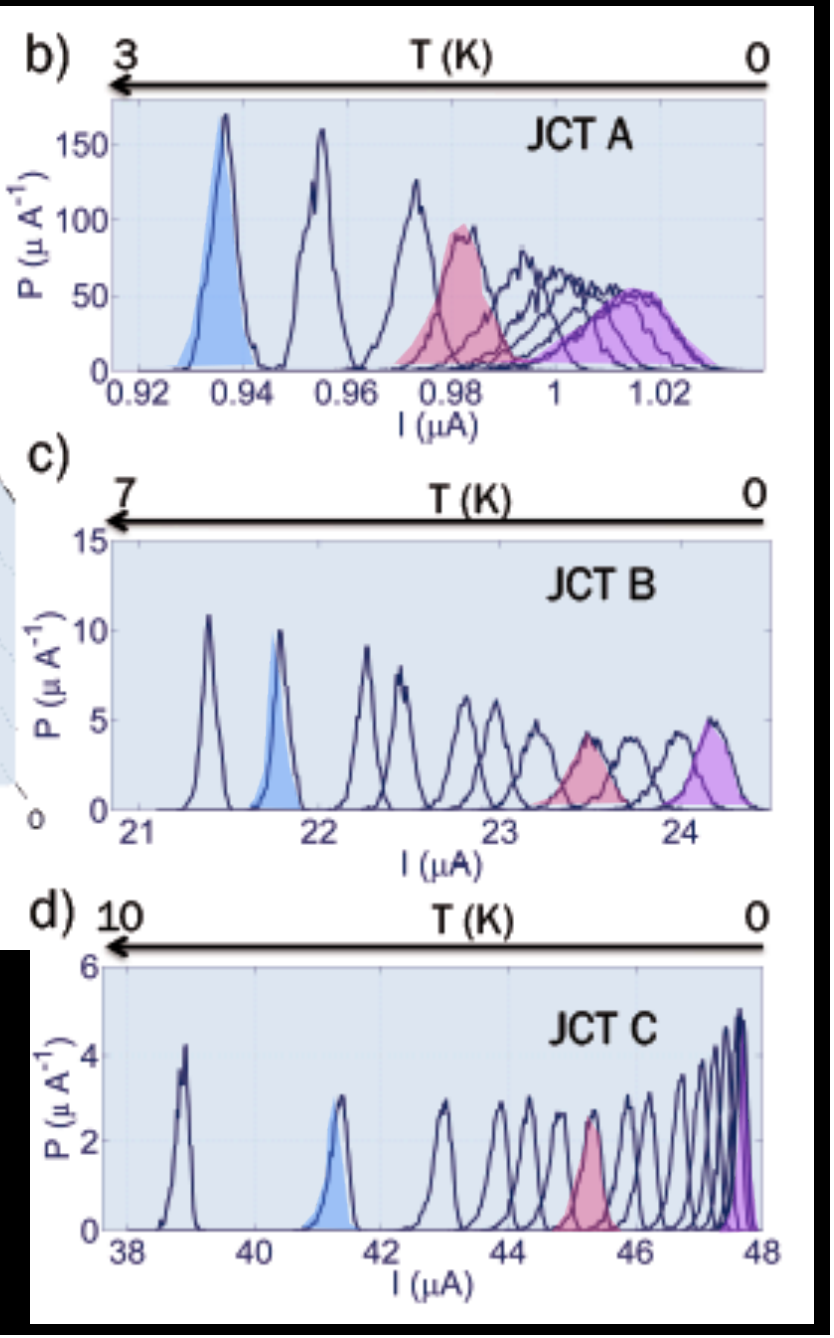




Phase diagram (E_J,T): the direct PD/MQT transition & the high-Jc limit

Pieces for the dissipation map: comparatively high-Jc





PHYSICAL REVIEW B **92**, 054501 (2015)

Breakdown of the escape dynamics in Josephson junctions

D. Massarotti,[1,2,*] D. Stornaiuolo,[1,2] P. Lucignano,[2] L. Galletti,[1,2] D. Born,[3] G. Rotoli,[4] F. Lombardi,[5] L. Longobardi,[4,6] A. Tagliacozzo,[1,2] and F. Tafuri[2,4]

[1]*Università degli Studi di Napoli "Federico II," Dipartimento di Fisica, via Cinthia, 80126 Napoli, Italy*
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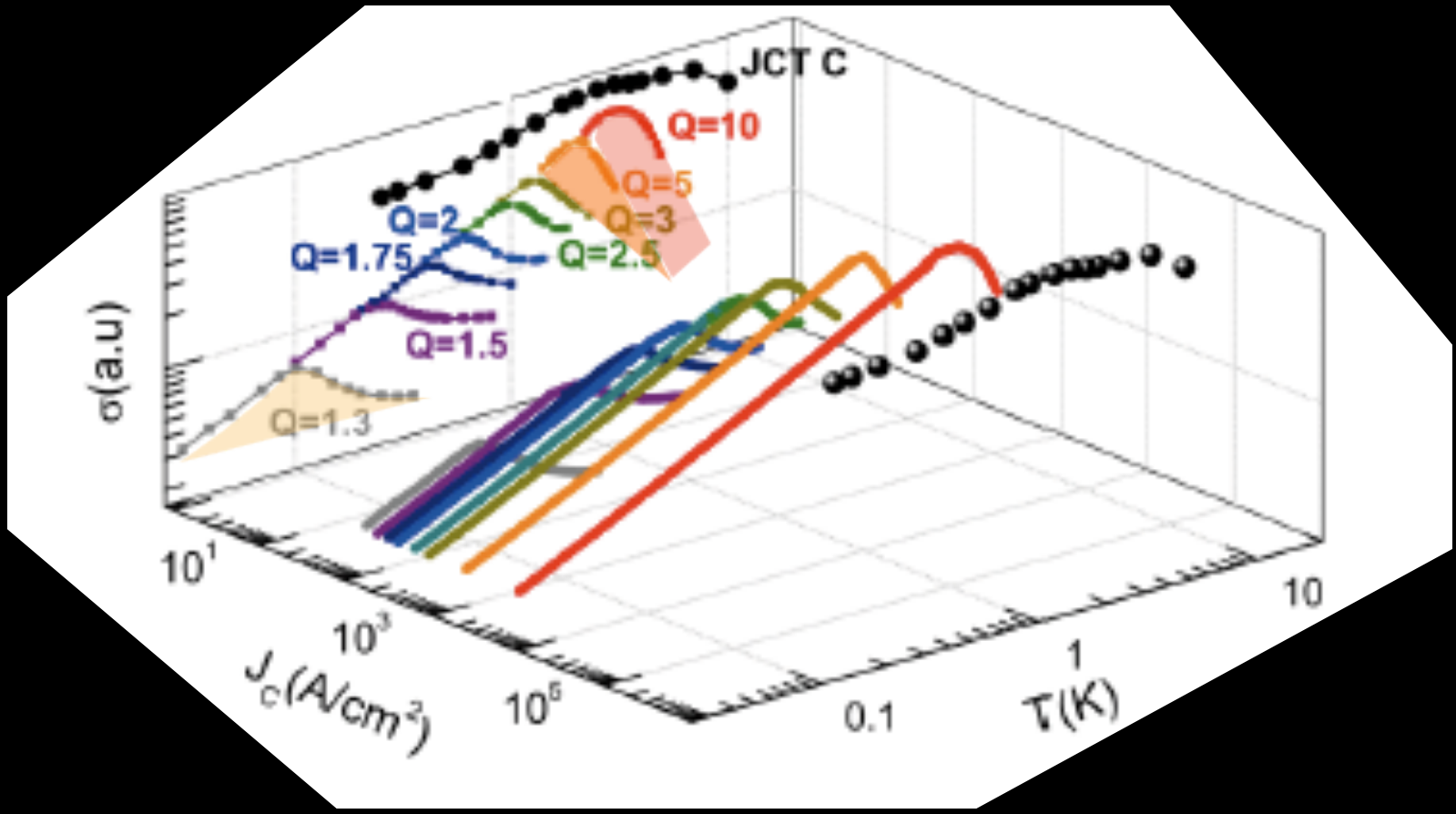
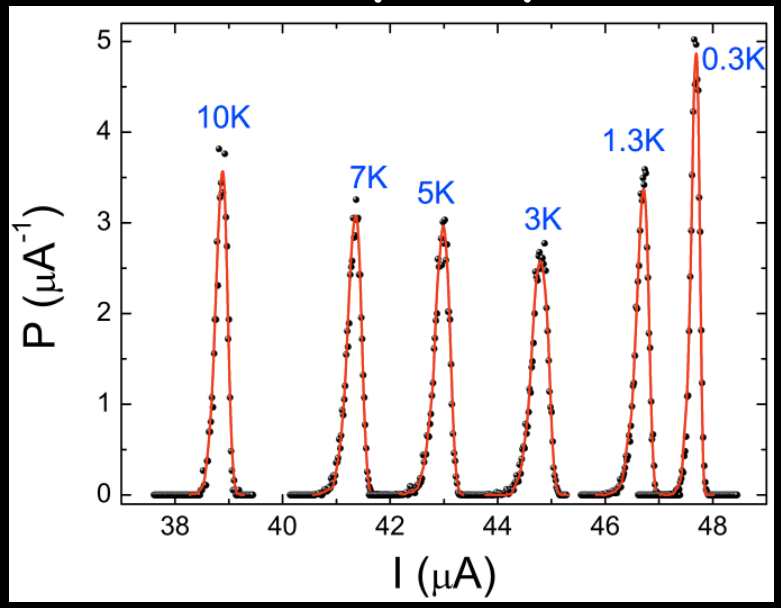
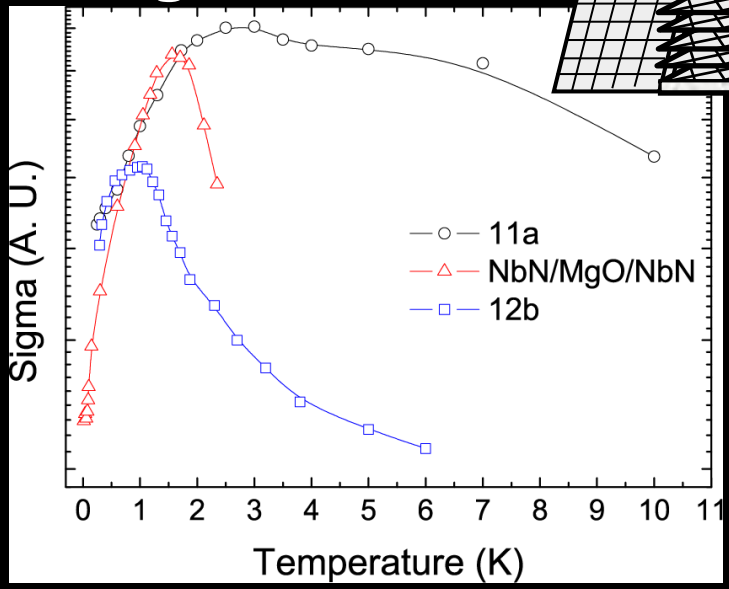
[3]*Leibniz Institute of Photonic Technology e.V., P.O. Box 100239, D-07702 Jena, Germany*
[4]*Seconda Università di Napoli, Dipartimento di Ingegneria Industriale e dell'Informazione, via Roma 29, 81031 Aversa (Ce), Italy*
[5]*Department of Microtechnology and Nanoscience, MC2, Chalmers University of Technology, S-41296 Göteborg, Sweden*
[6]*American Physical Society, 1 Research Road, Ridge, New York 11961, USA*

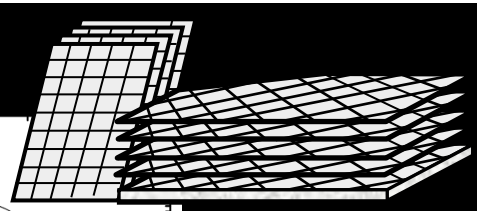
What happens for high Jc?



Escape dynamics in high-Jc JJs



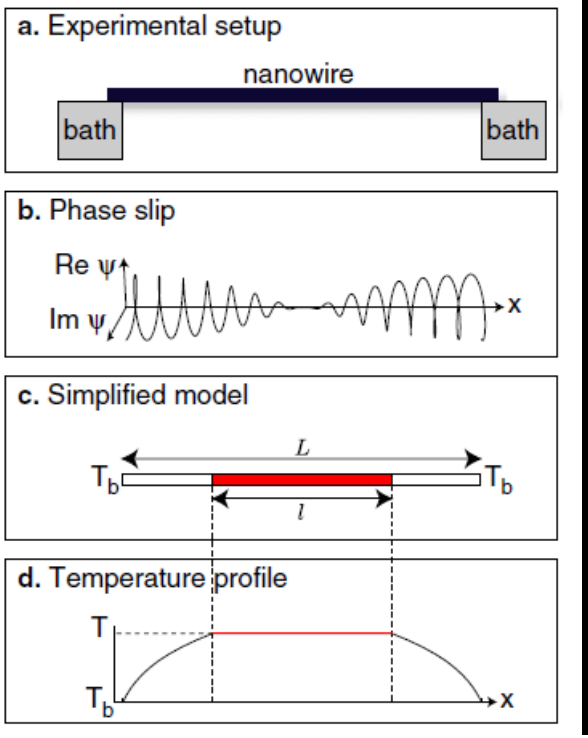




D. Massarotti, D. Stornaiuolo, L. Galletti et al.
Phys. Rev. B (2015)

$$\frac{dT}{dt} = -\alpha(T, T_b)(T - T_b) + \eta(T, I)\sum_i \delta(t - t_i).$$

$$\alpha(T, T_b) \equiv \frac{4}{l(L-l)C_v(T)} \frac{1}{T - T_b} \int_{T_b}^{T} dT' K_s(T').$$

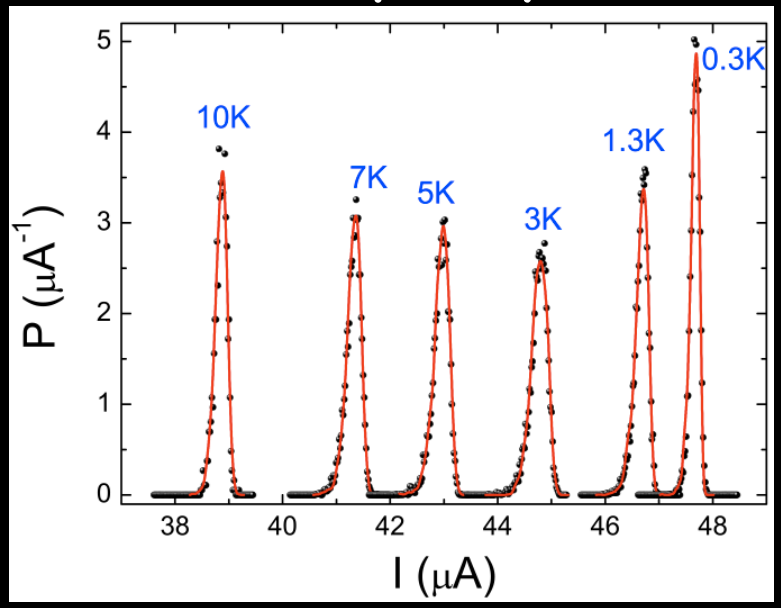


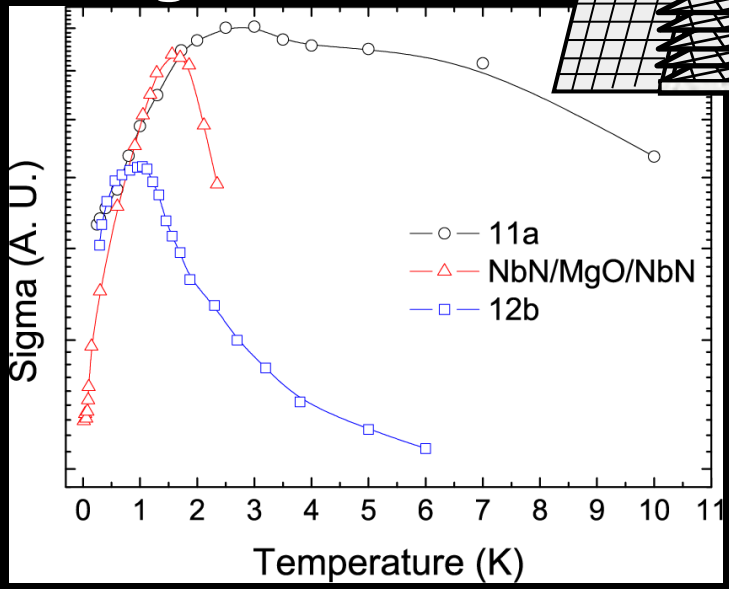
PRL **101,** 207001 (2008) PHYSICAL REVIEW LETTERS week ending 14 NOVEMBER 2008

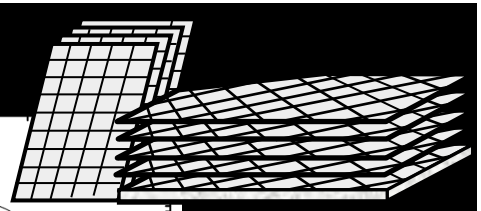
Inherent Stochasticity of Superconductor-Resistor Switching Behavior in Nanowires

Nayana Shah, David Pekker, and Paul M. Goldbart

Escape dynamics in high-Jc JJs



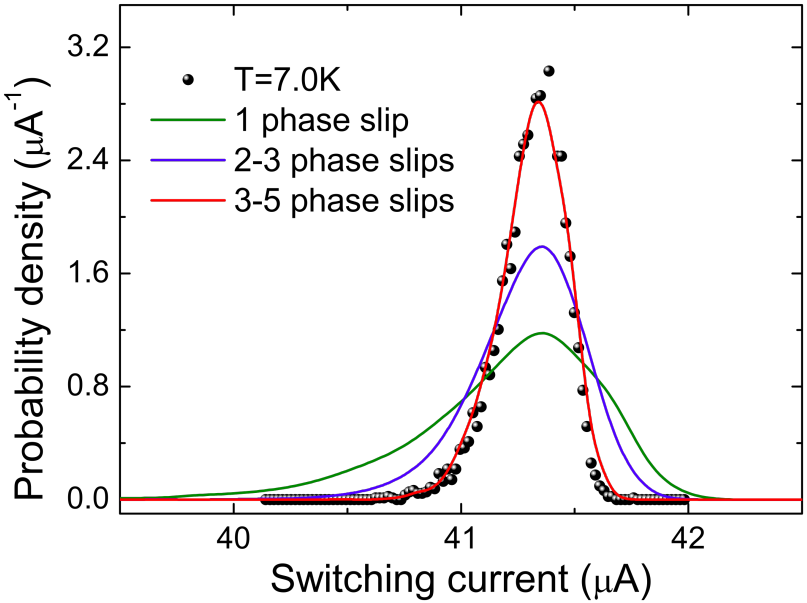




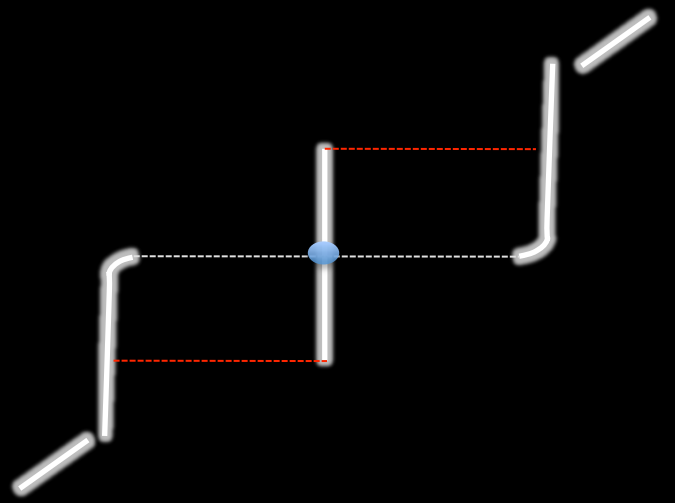
D. Massarotti, D. Stornaiuolo, L. Galletti et
Phys. Rev. B (2015)

$$\frac{dT}{dt} = -\alpha(T, T_b)(T - T_b) + \eta(T, I)\sum_i \delta(t - t_i).$$

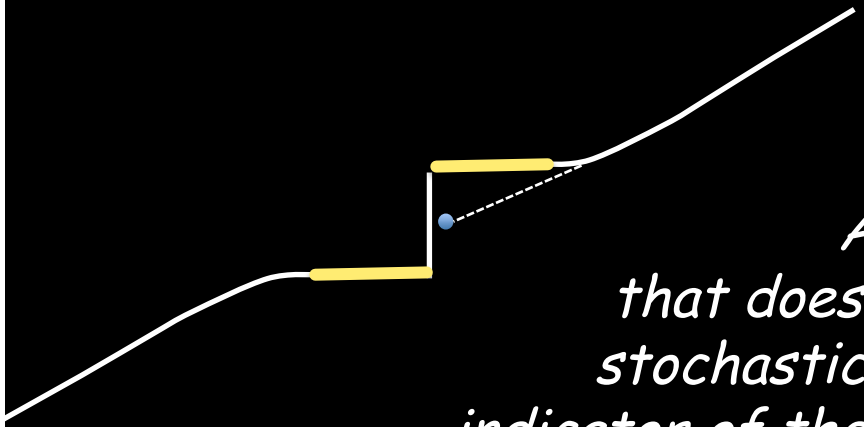
$$\alpha(T, T_b) \equiv \frac{4}{l(L-l)C_v(T)} \frac{1}{T - T_b} \int_{T_b}^{T} dT' K_s(T').$$



The physical meaning



'Collapse' of the Josephson effect driven
by a too large J_c i.e. by non-equilibrium effects.



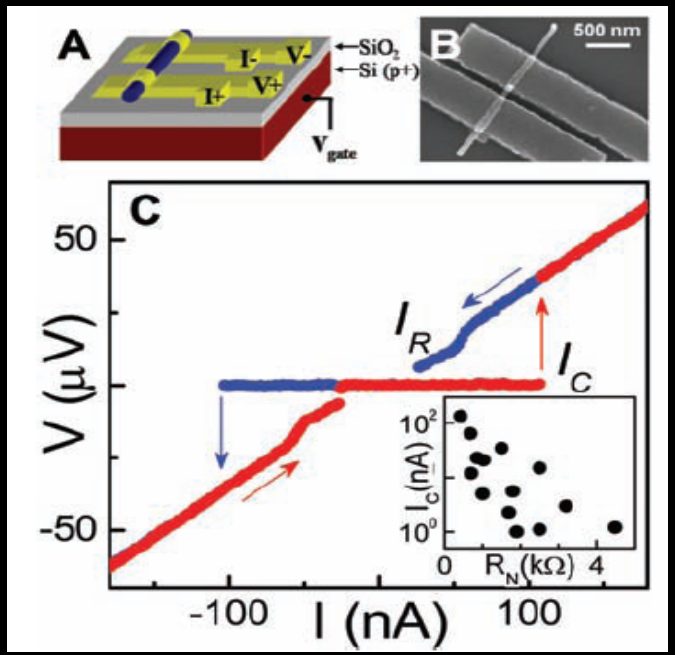
A switching behavior from S to N,
that does not follow the standard
stochastic Josephson phase dynamics, is the main
indicator of the onset of non-equilibrium effects.

How much 'coupling' can be sustained for a phase-carrying current ?!

8 JULY 2005 VOL 309 SCIENCE

Tunable Supercurrent Through Semiconductor Nanowires

Yong-Joo Doh,[1]* Jorden A. van Dam,[1]* Aarnoud L. Roest,[1,2]
Erik P. A. M. Bakkers,[2] Leo P. Kouwenhoven,[1]
Silvano De Franceschi[1]†



PHYSICAL REVIEW B VOLUME 60, NUMBER 18 1 NOVEMBER 1999-II

Critical currents in ballistic two-dimensional InAs-based superconducting weak links

J. P. Heida, B. J. van Wees, and T. M. Klapwijk
Department of Applied Physics and Material Science Centre, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

G. Borghs
Interuniversity Microelectronics Centre, Kapeldreef 75, B-3030, Leuven, Belgium
(Received 4 January 1999; revised manuscript received 4 August 1999)

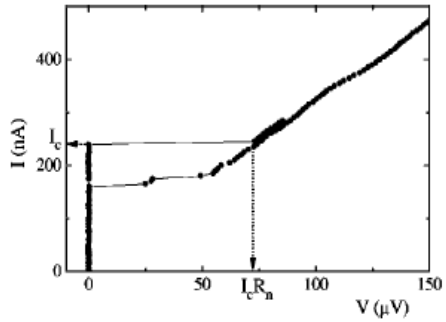


FIG. 1. Current-voltage characteristic for sample No. 4 illustrating the experimental definitions of I_c and I_cR_n, indicated by arrows (T=0.7 K).

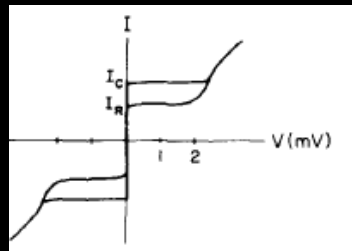


FIG. 4. *I-V* characteristic of a high-current-density (4×10^5 A/cm^2) junction.

High-quality submicron niobium tunnel junctions with reactive-ion-beam oxidation

A. W. Kleinsasser and R. A. Buhrman
School of Applied and Engineering Physics, Materials Science Center, and National Research and Resource Facility for Submicron Structures, Cornell University, Ithaca, New York 14853

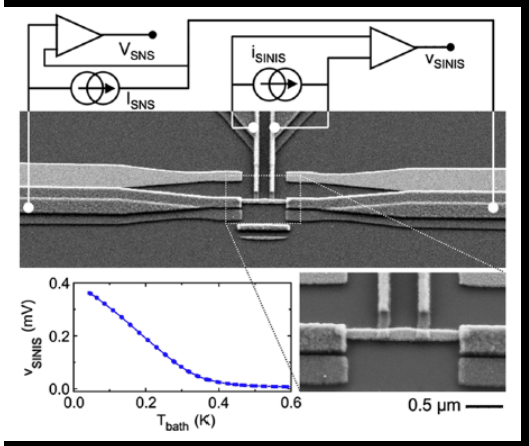
841 Appl. Phys. Lett. 37(9), 1 November 1980

How much 'coupling' can be sustained for a phase-carrying current ?!

PRL 101, 067002 (2008) PHYSICAL REVIEW LETTERS week ending 8 AUGUST 2008

Origin of Hysteresis in a Proximity Josephson Junction

H. Courtois,[1,2] M. Meschke,[1] J. T. Peltonen,[1] and J. P. Pekola[1]
[1]*Low Temperature Laboratory, Helsinki University of Technology, P.O. Box 3500, 02015 TKK, Finland*
[2]*Institut Néel, CNRS and Université Joseph Fourier, 25 Avenue des Martyrs, BP 166, 38042 Grenoble, France*
(Received 29 May 2008; published 8 August 2008)



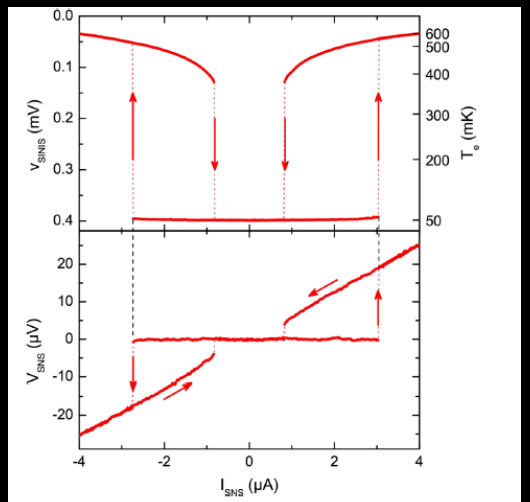


FIG. 2 (color online). Current-voltage characteristic of the sample 1 S-N-S junction (bottom panel) shown on the same current scale with the S-I-N-I-S thermometer voltage response (top panel) measured simultaneously at a 50 mK cryostat temperature. In the top panel, the right vertical axis gives the corresponding electron temperature.

Phase slips and switching dynamics in nanowires

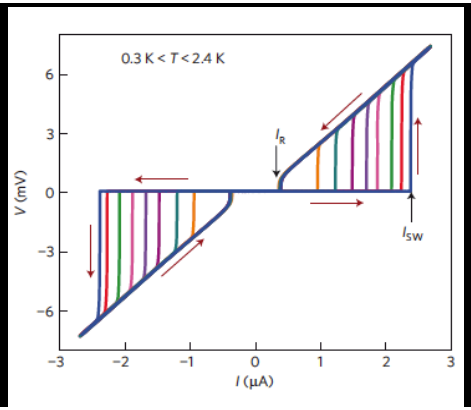
nature physics

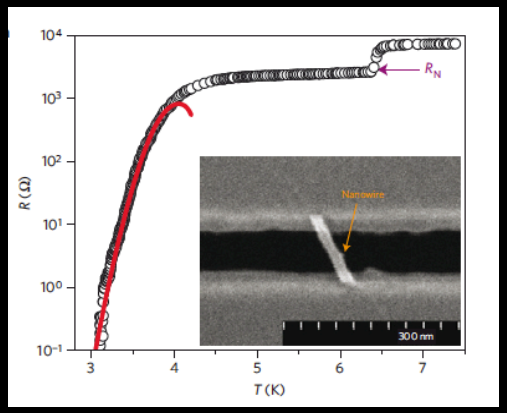
ARTICLES

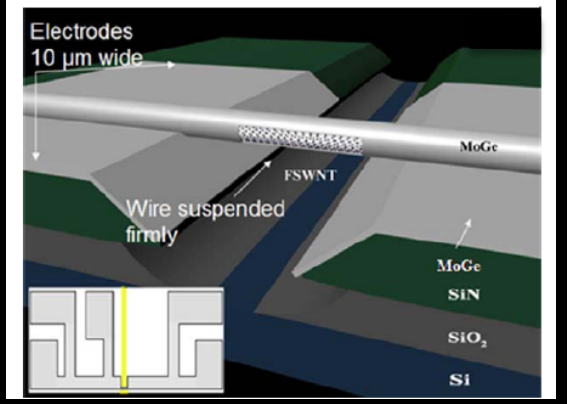
PUBLISHED ONLINE: 17 MAY 2009 | DOI:10.1038/NPHYS1276

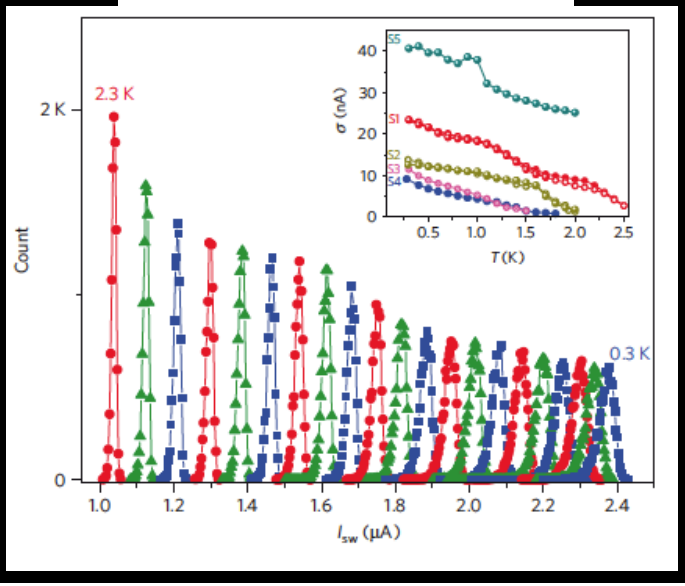
Individual topological tunnelling events of a quantum field probed through their macroscopic consequences

Mitrabhanu Sahu[1]*, Myung-Ho Bae[1], Andrey Rogachev[1,2], David Pekker[1,3], Tzu-Chieh Wei[1,4], Nayana Shah[1], Paul M. Goldbart[1] and Alexey Bezryadin[1]





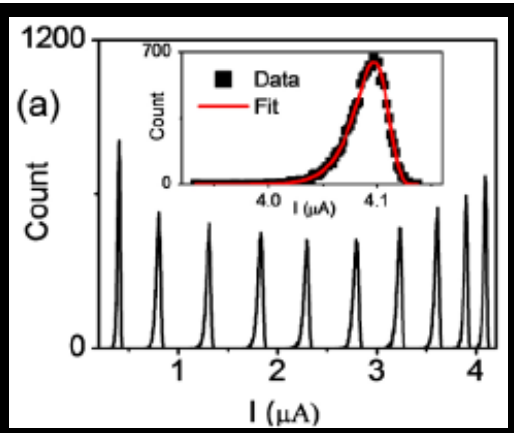


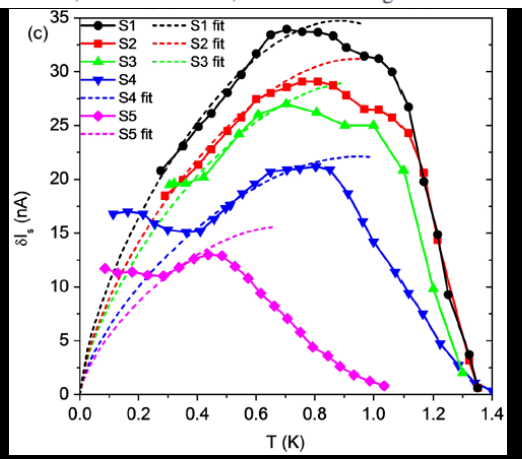


PRL 107, 137004 (2011) PHYSICAL REVIEW LETTERS week ending 23 SEPTEMBER 2011

Switching Currents Limited by Single Phase Slips in One-Dimensional Superconducting Al Nanowires

Peng Li, Phillip M. Wu, Yuriy Bomze, Ivan V. Borzenets, Gleb Finkelstein, and A. M. Chang*





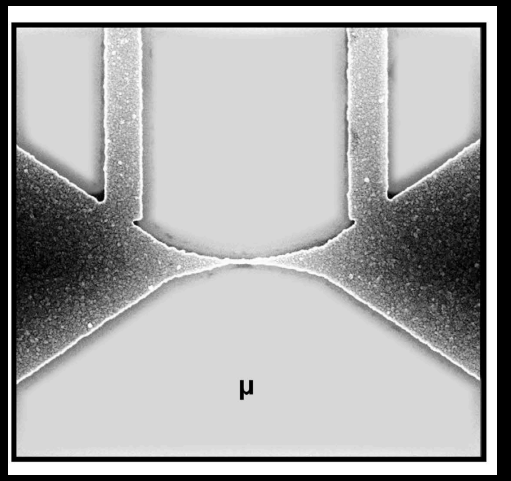
SCIENTIFIC REPORTS

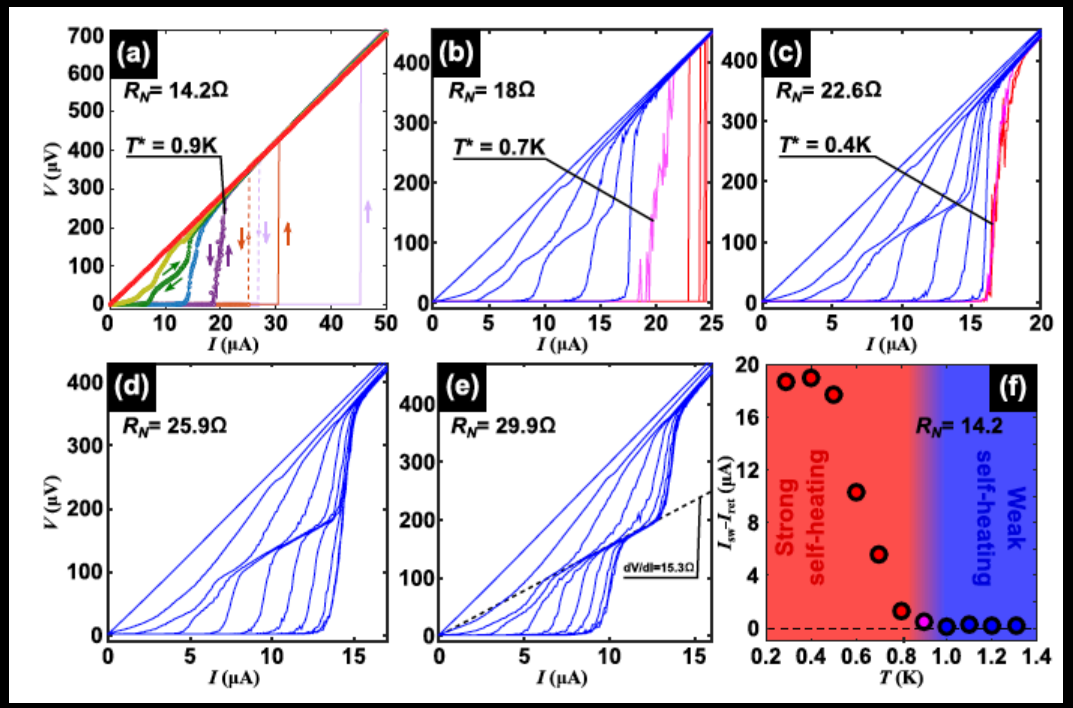
OPEN

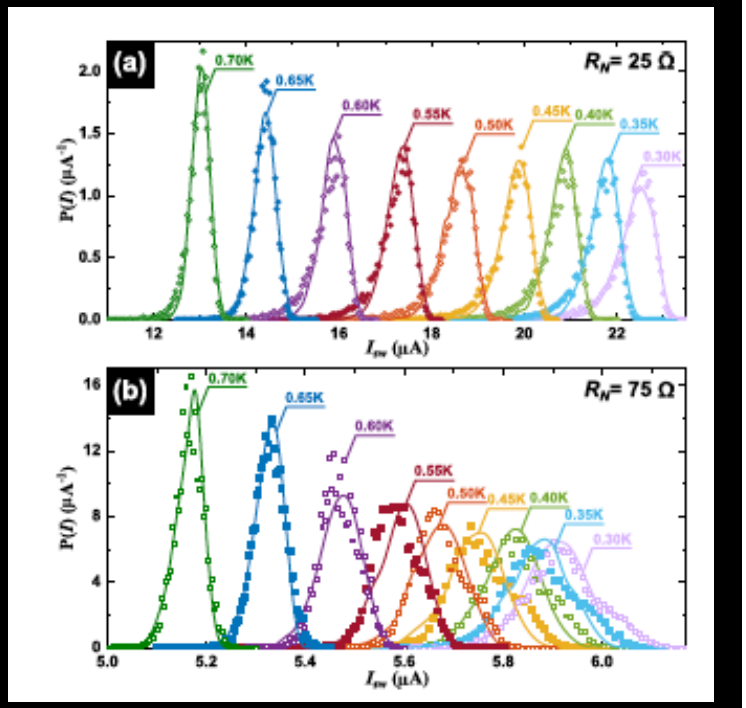
Statistics of localized phase slips in tunable width planar point contacts

Xavier D.A. Baumans[1], Vyacheslav S. Zharinov[2], Eline Raymenants[2], Sylvain Blanco Alvarez[1], Jeroen E. Scheerder[2], Jérémy Brisbois[1], Davide Massarotti[3,4], Roberta Caruso[4,5], Francesco Tafuri[4,5], Ewald Janssens[6], Victor V. Moshchalkov[2], Joris Van de Vondel[2] & Alejandro V. Silhanek[1]

Received: 24 November 2016
Accepted: 09 February 2017

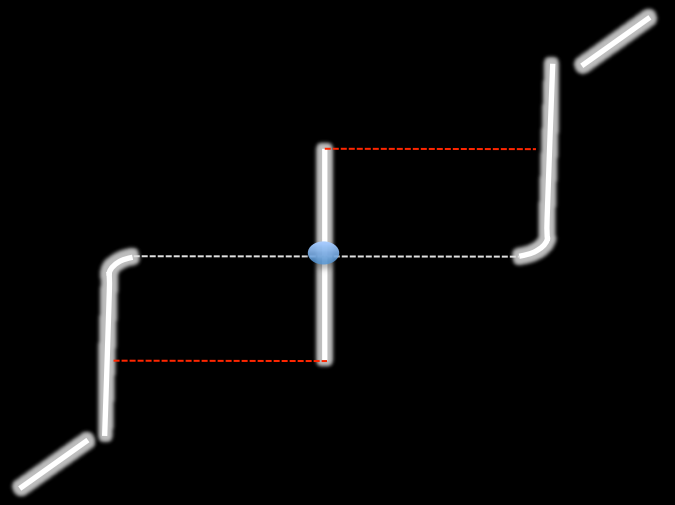


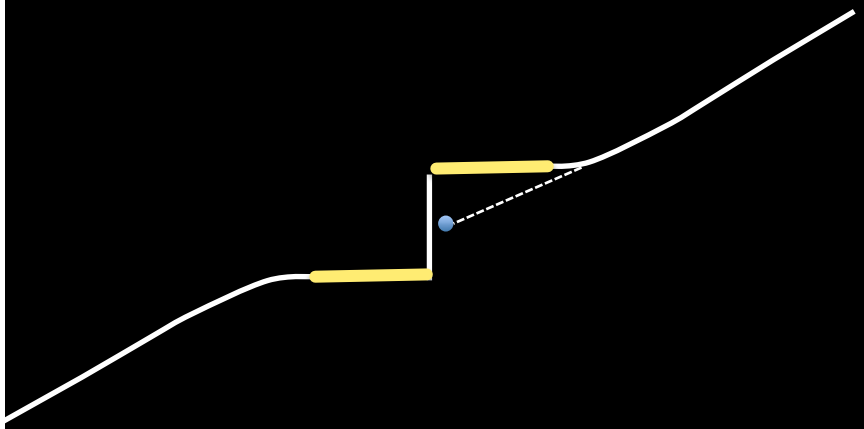




Conclusions

Importance of decoding fluctuations





Conclusions

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