



Half-integer Shapiro steps in highly transmissive InSb nanoflag Josephson junctions

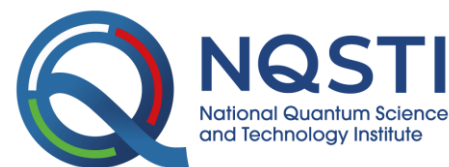
Andrea Iorio¹, Alessandro Crippa¹, Bianca Turini¹, Sedighe Salimian¹,
Matteo Carrega², Luca Chirolli¹, Valentina Zannier¹, Lucia Sorba¹,
Elia Strambini¹, Francesco Giazotto¹, and **Stefan Heun**¹

¹NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Pisa, Italy

²CNR-SPIN, Via Dodecaneso 33, 16146 Genoa, Italy

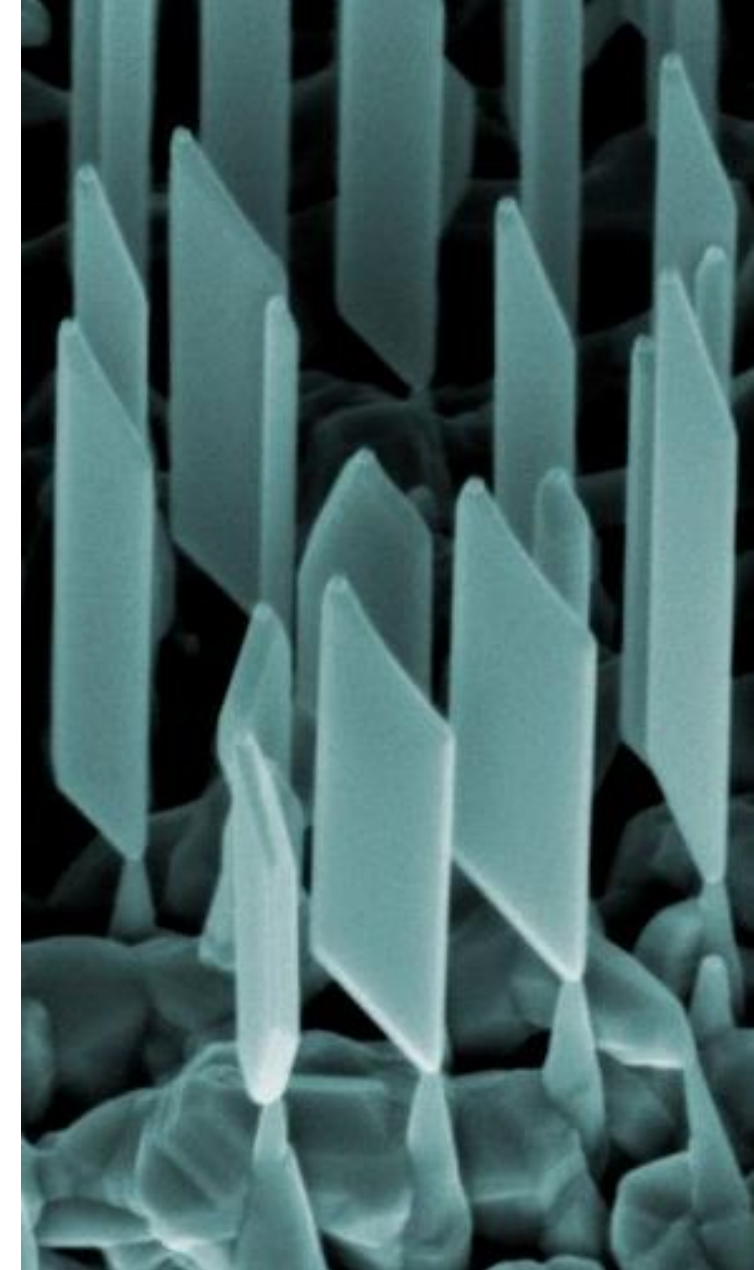


AndQC



National Enterprise for nanoScience and nanoTechnology

NEST



Why InSb?

Small bandgap

$$E_g = 0.23 \text{ eV}$$

Low effective mass

$$m/m_0 = 0.018$$

Strong SOC

$$E_{\text{SOC}} \sim 200 \text{ } \mu\text{eV}$$

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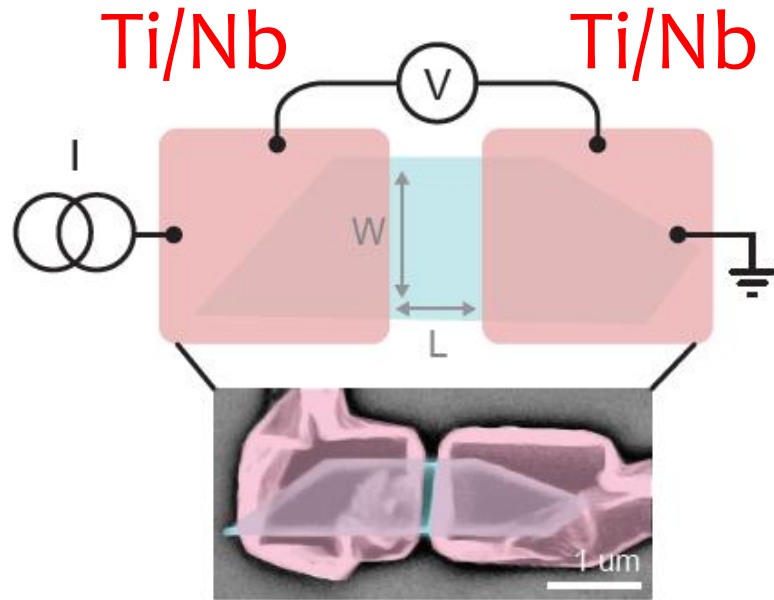
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High-mobility 2D nanostructures

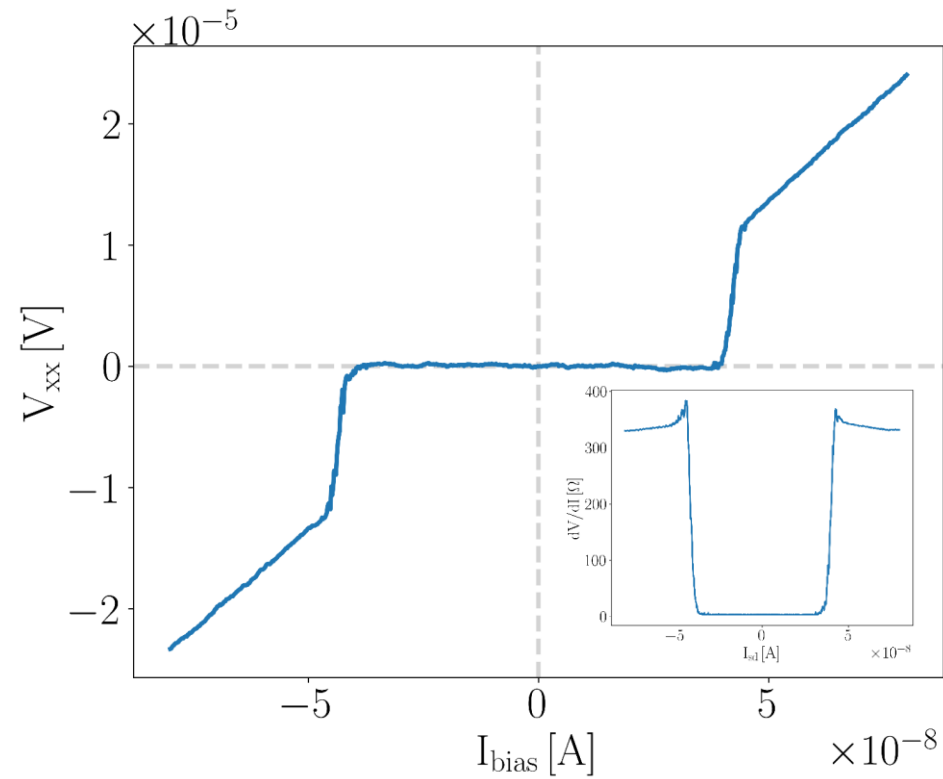


InSb nanoflag-based Josephson junctions



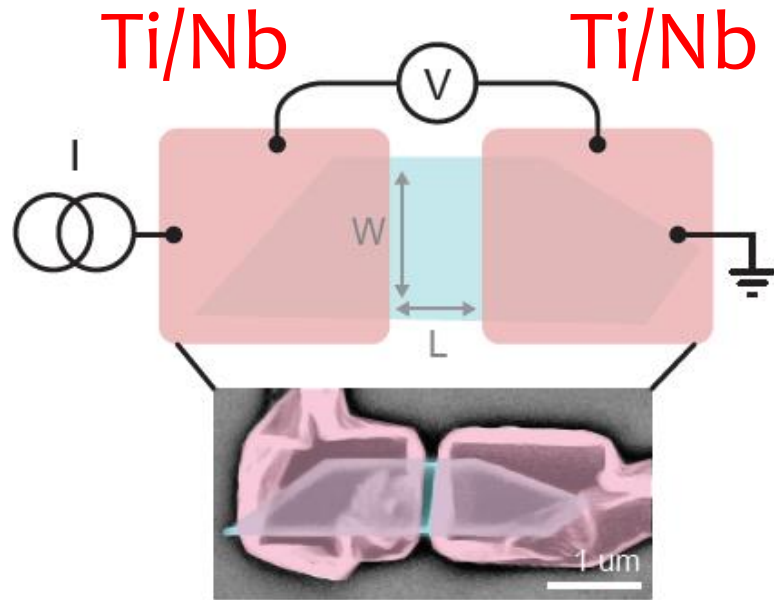
λ_{mfp}	500 nm
L	200 nm
ξ_S	750 nm

short-ballistic junction

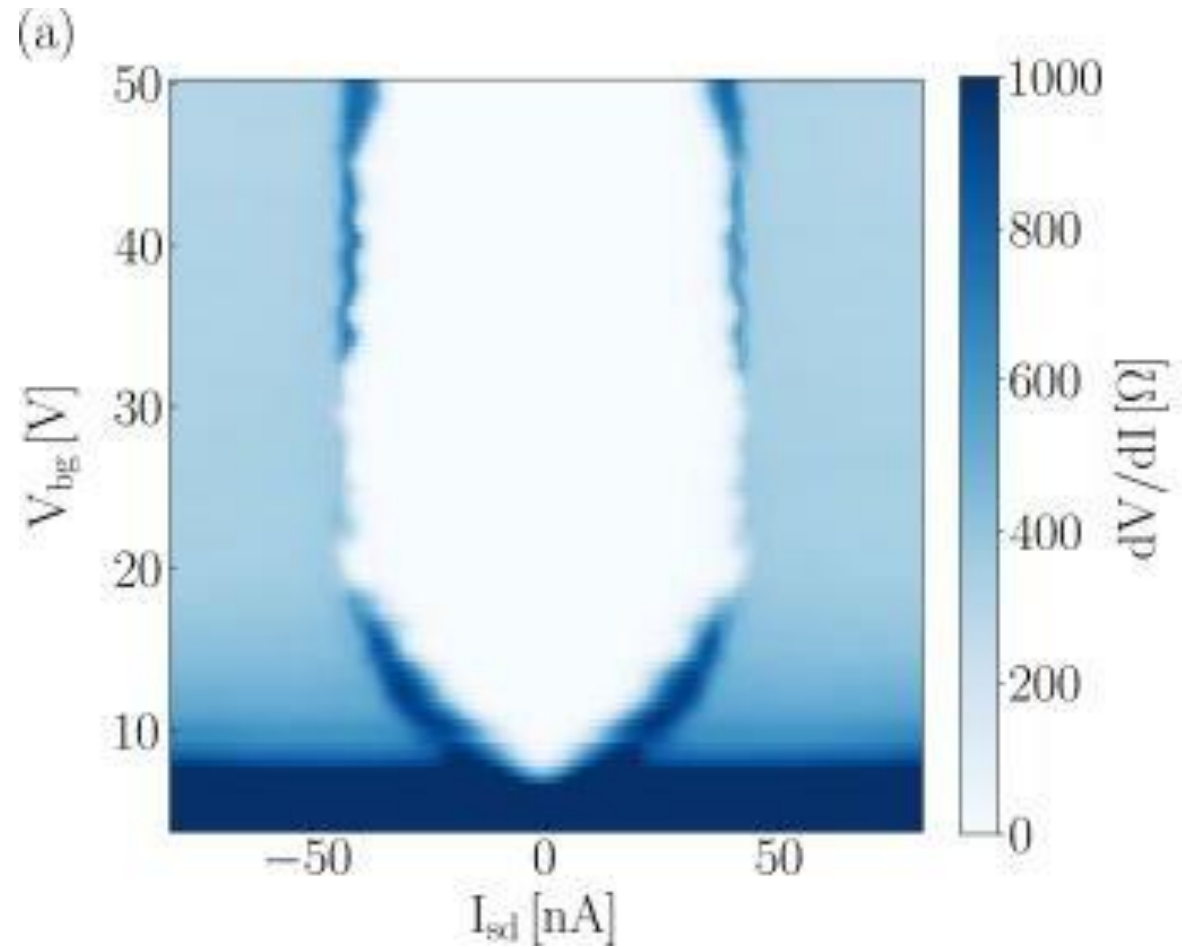


Sedighe Salimian

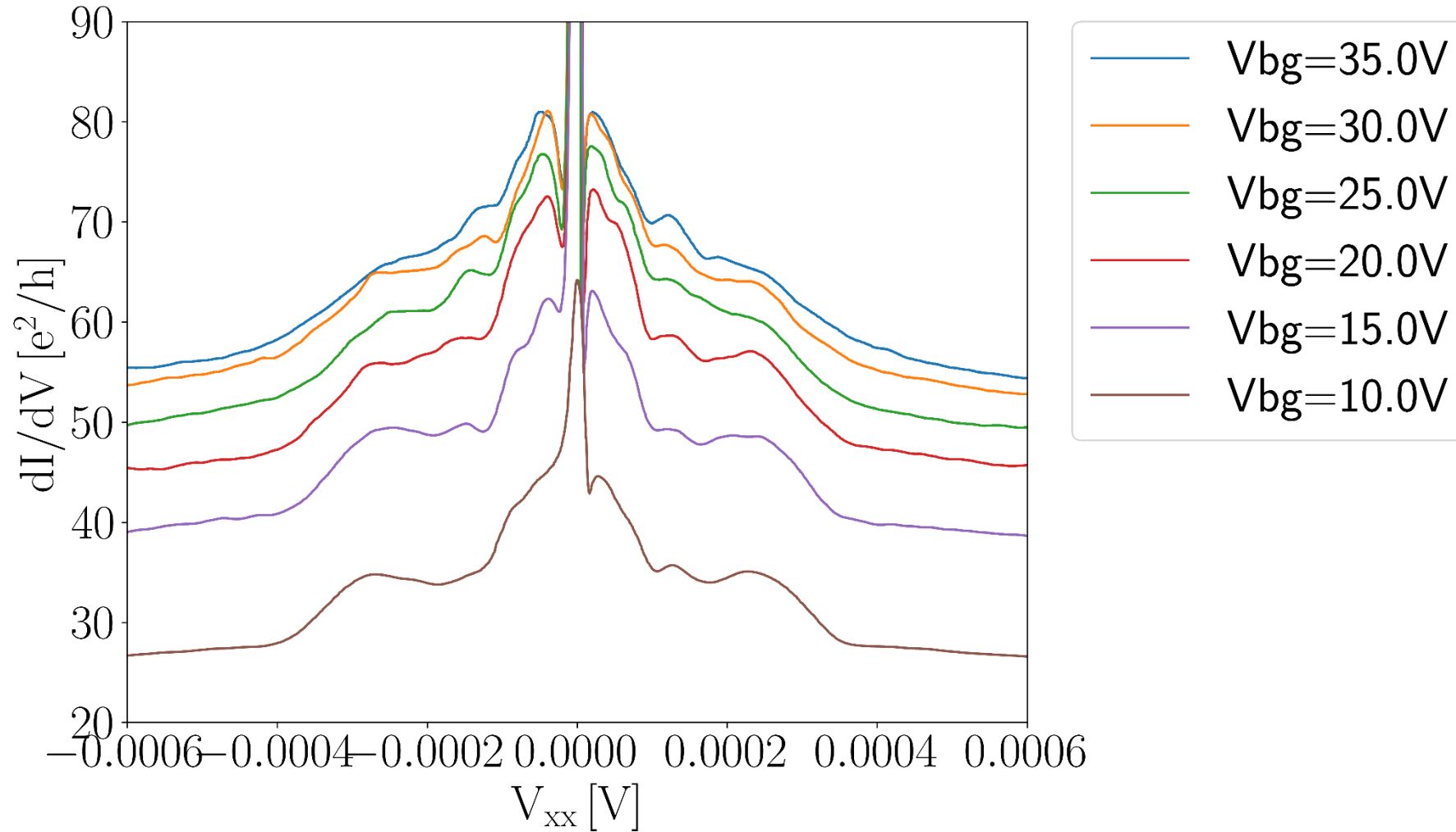
Gate-tunable supercurrent



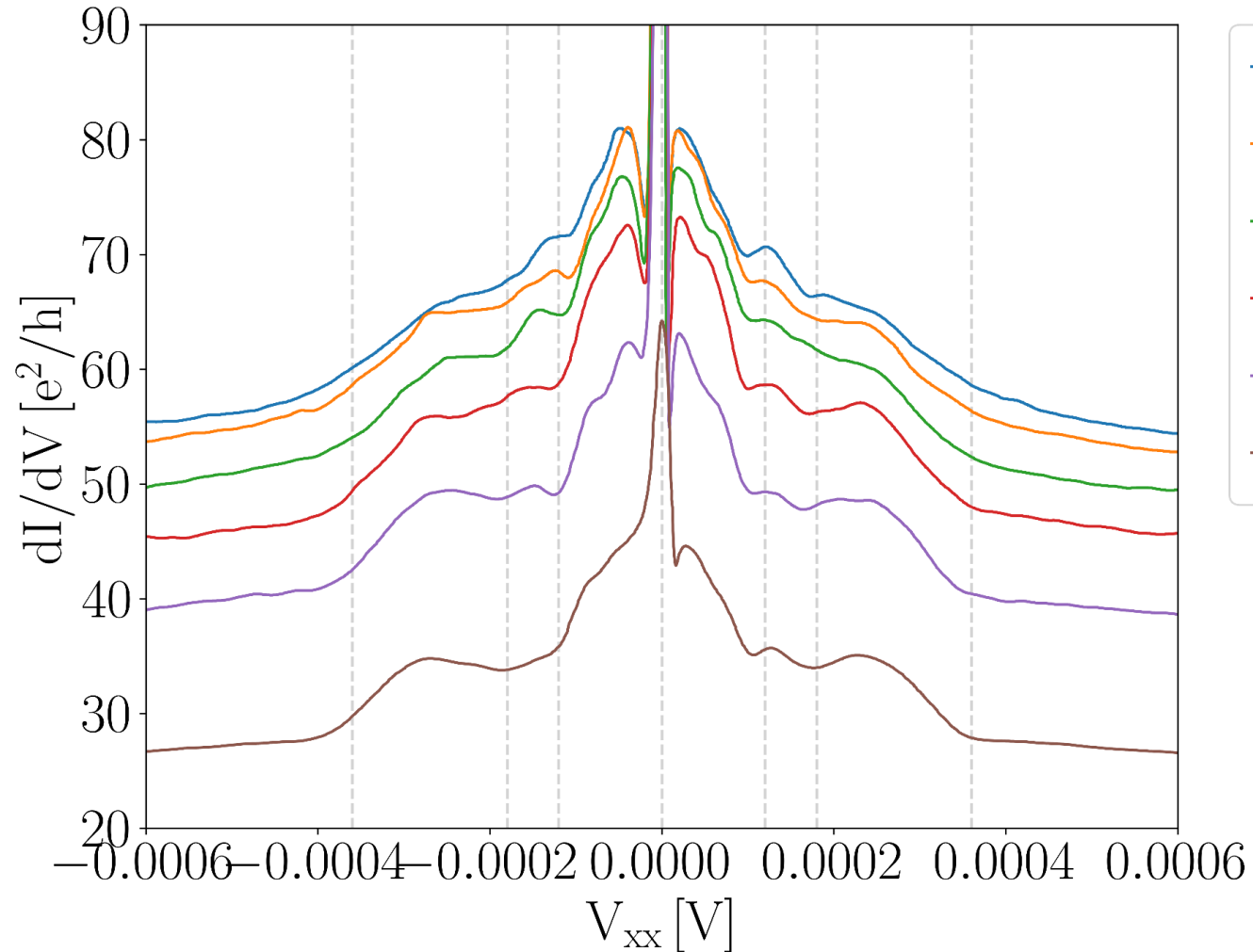
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Multiple Andreev Reflections



Multiple Andreev Reflections



- $V_{bg}=35.0V$
- $V_{bg}=30.0V$
- $V_{bg}=25.0V$
- $V_{bg}=20.0V$
- $V_{bg}=15.0V$
- $V_{bg}=10.0V$



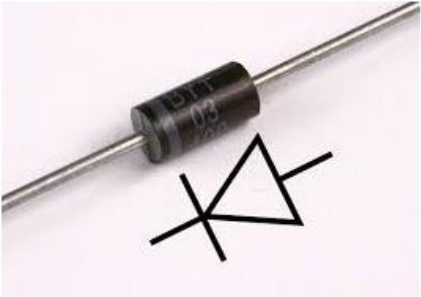
Michal P. Nowak

$$eV(n) = 2\Delta^*/n \quad (n=1, 2, 3 \dots)$$

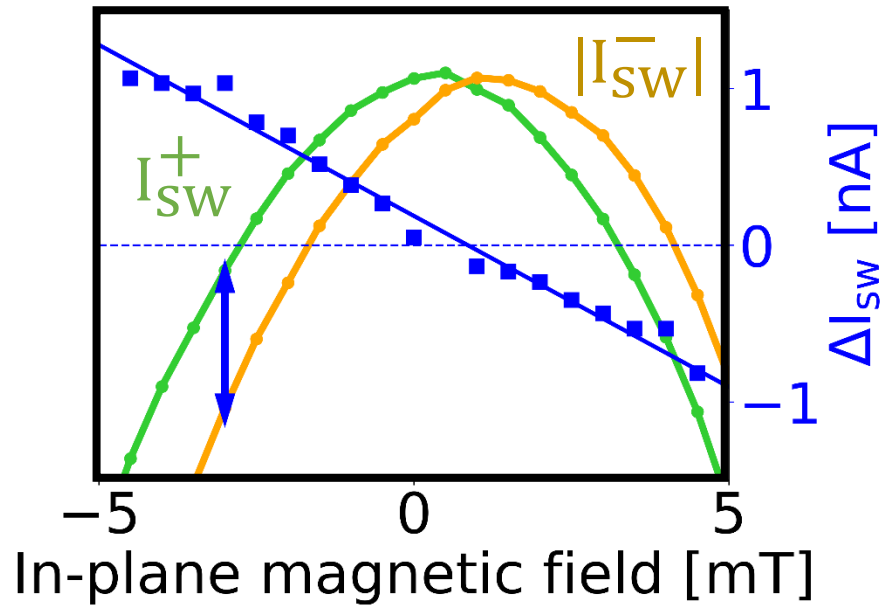
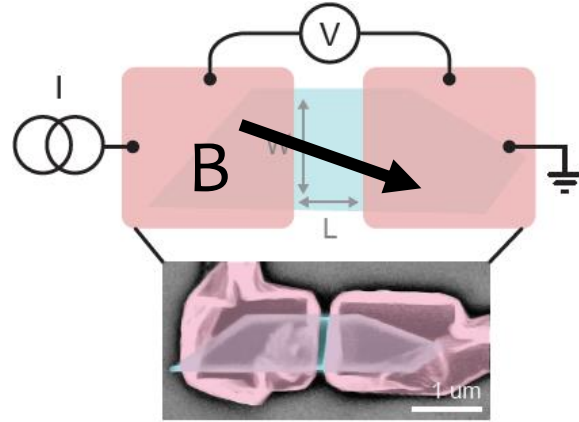
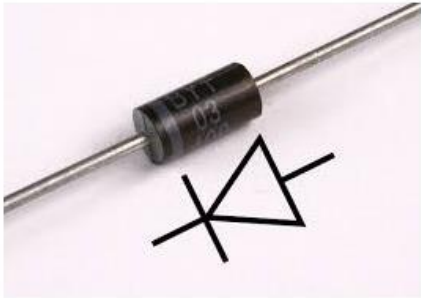
$$\Delta^* \sim 160 \mu eV$$

transparency $\tau = 0.94$

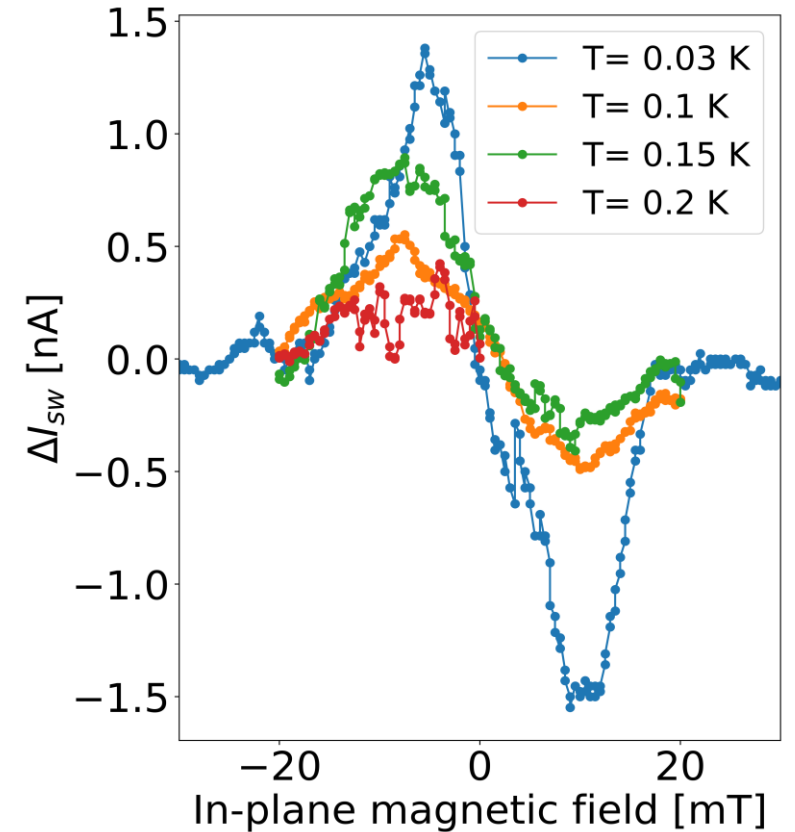
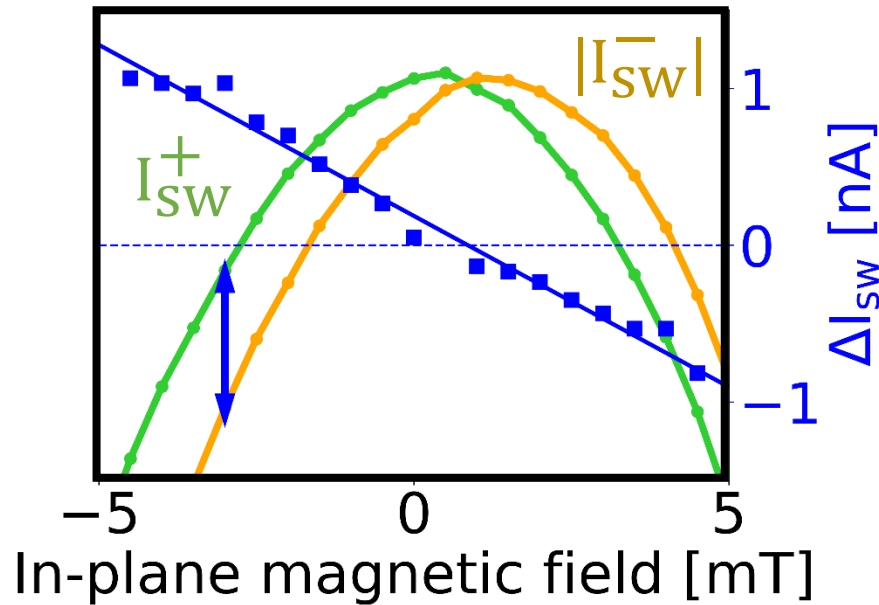
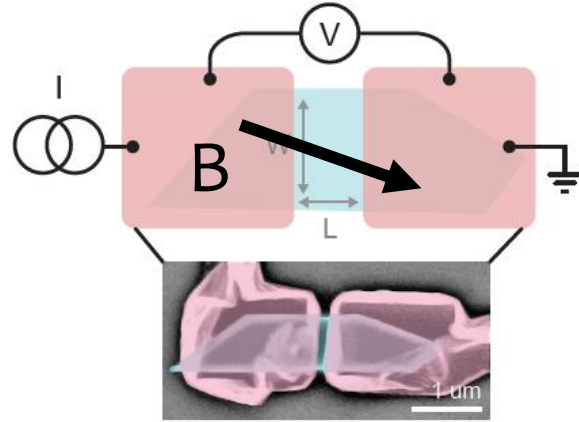
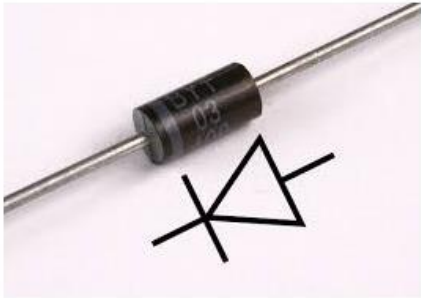
Josephson Diode Effect



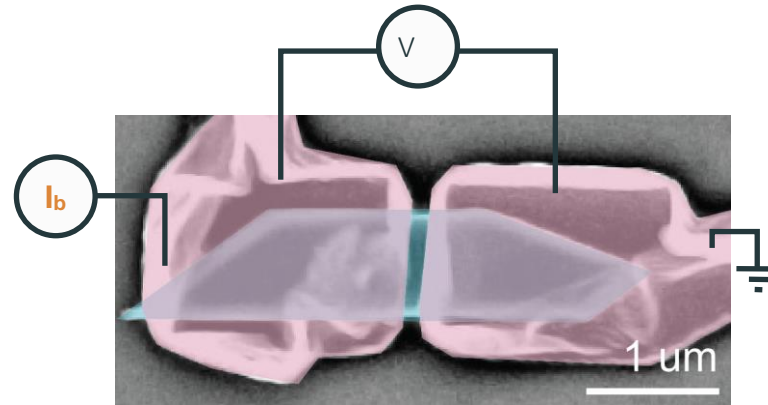
Josephson Diode Effect



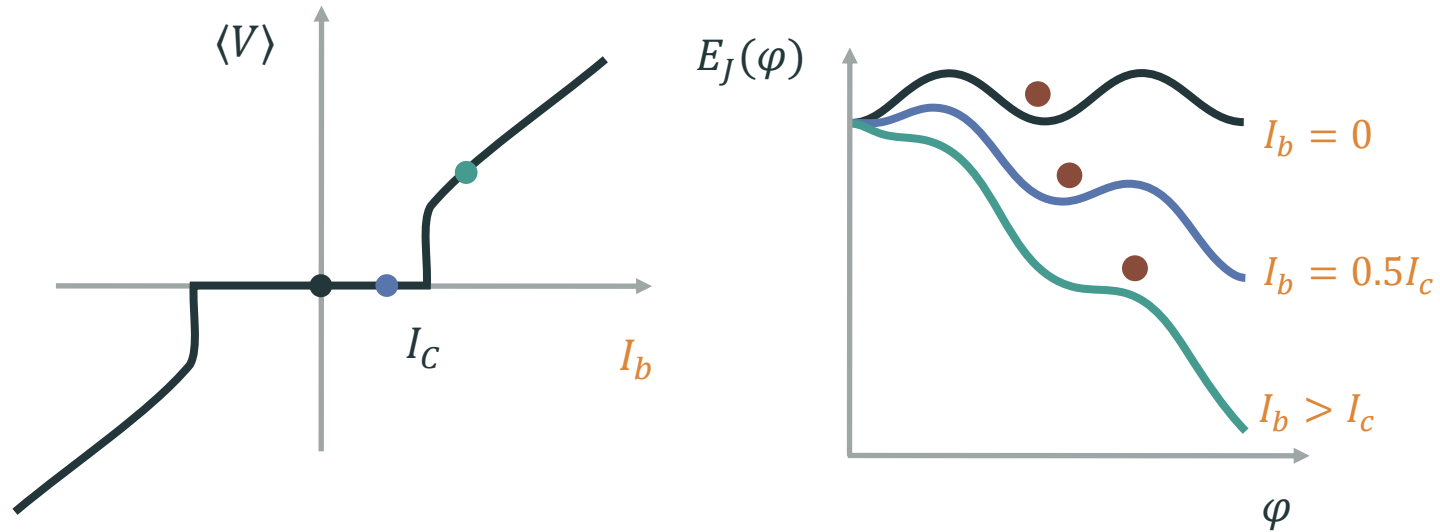
Josephson Diode Effect



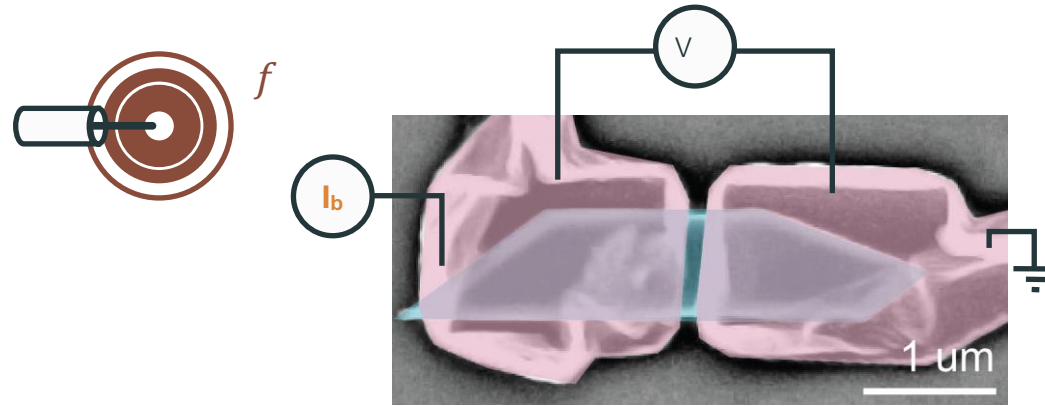
Shapiro steps



$$V = \frac{\hbar}{2e} \dot{\varphi}$$

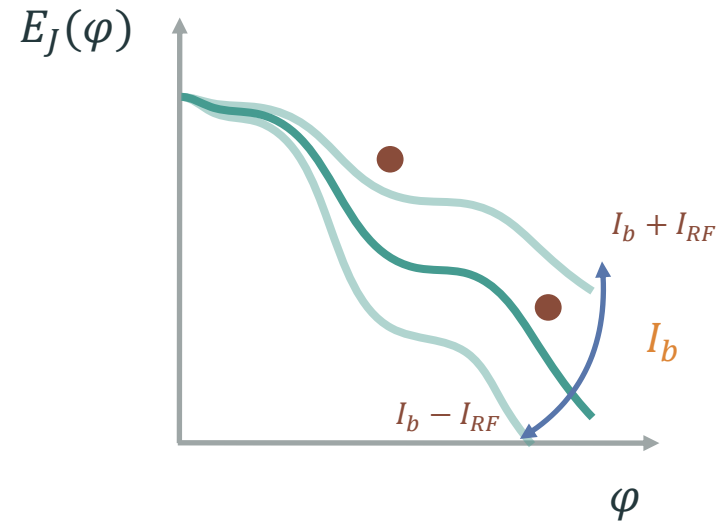
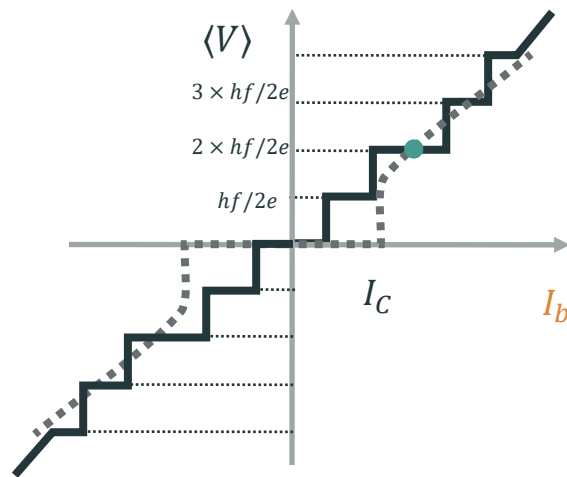


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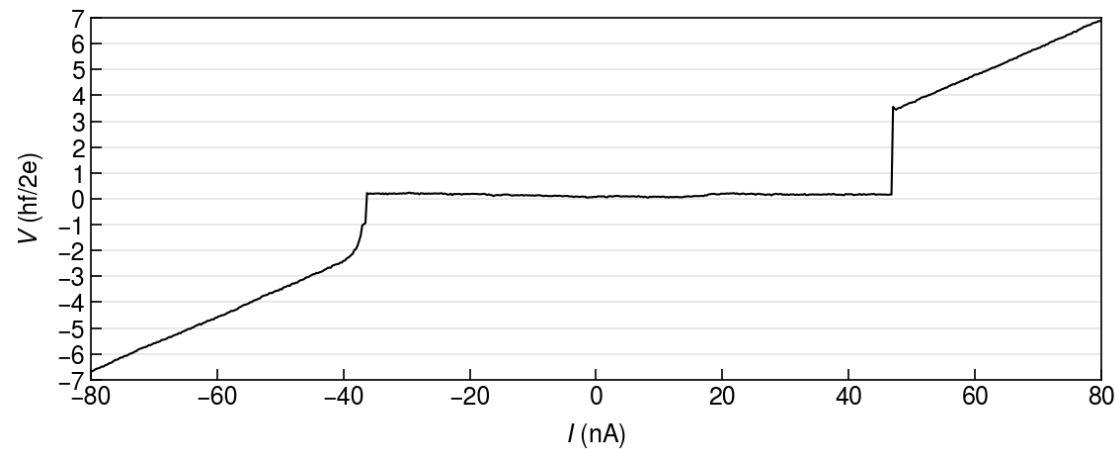
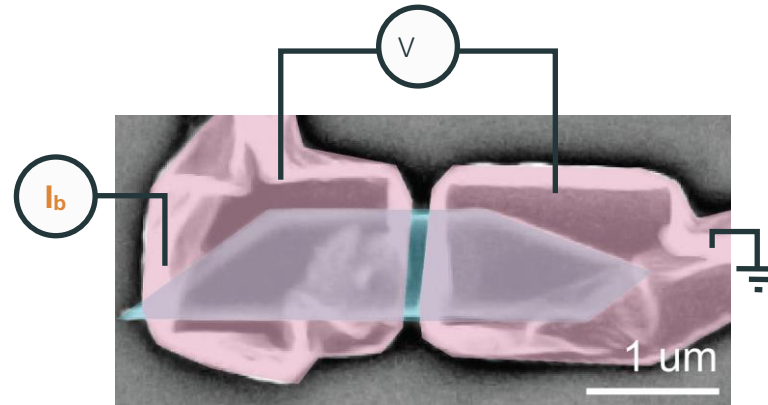


If particle rolls n minima in a period $T = 2\pi/f$, then $\dot{\varphi} = 2\pi n f$

$$V = \frac{\hbar}{2e} \dot{\varphi} = \frac{hf}{2e} n$$

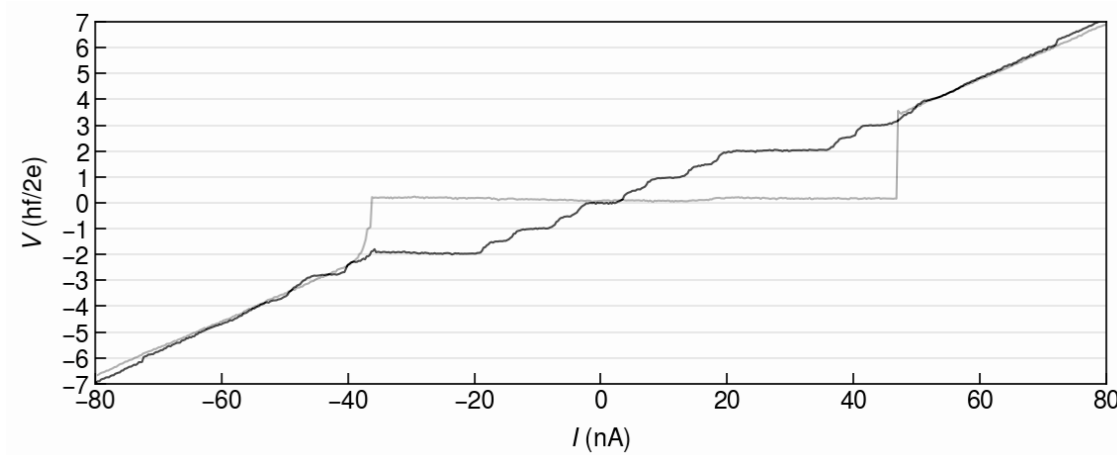
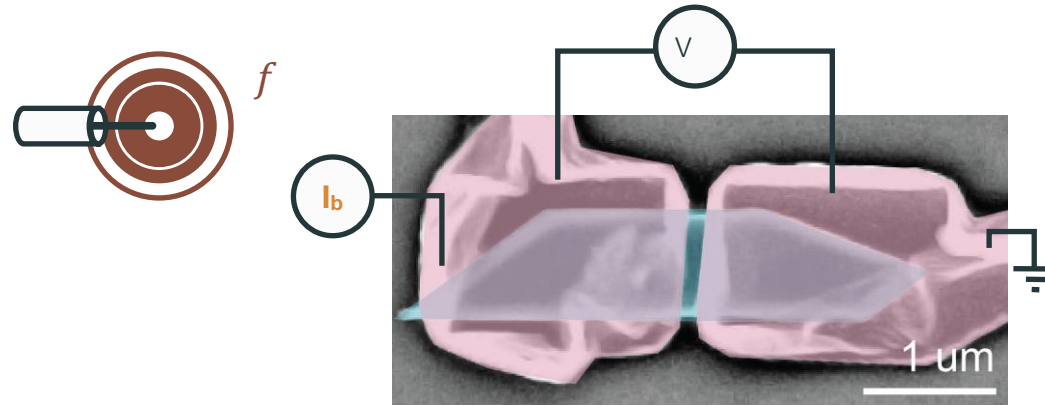


Half-integer Shapiro steps



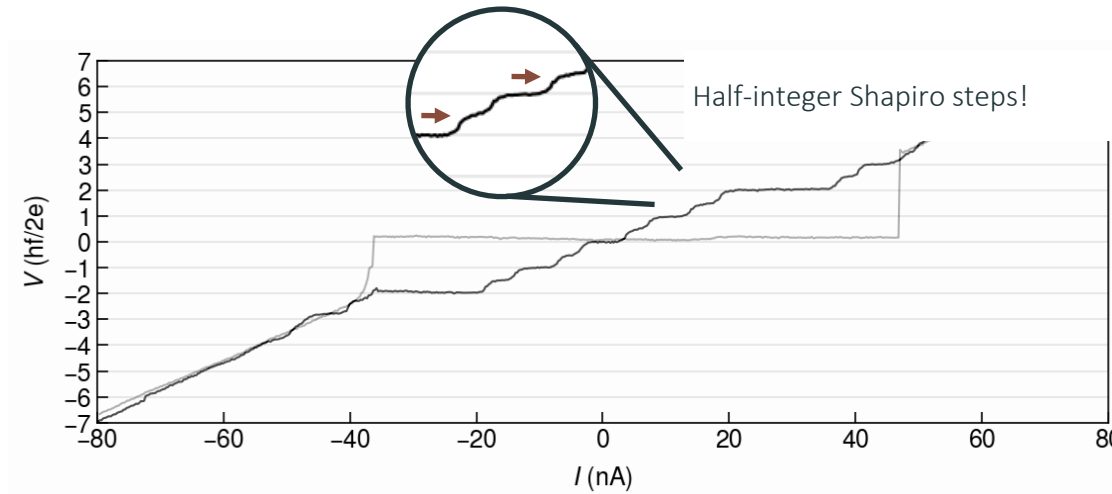
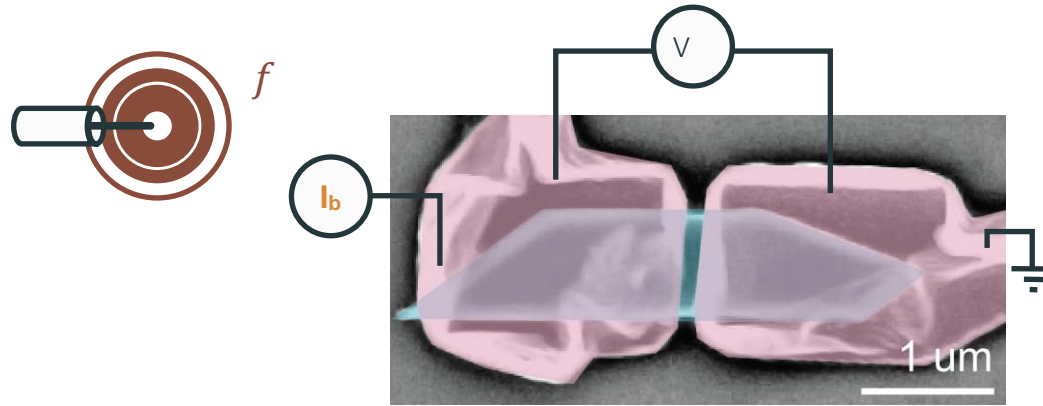
Shapiro steps – Quantized voltage plateaus $V = \frac{hf}{2e} n$

Half-integer Shapiro steps



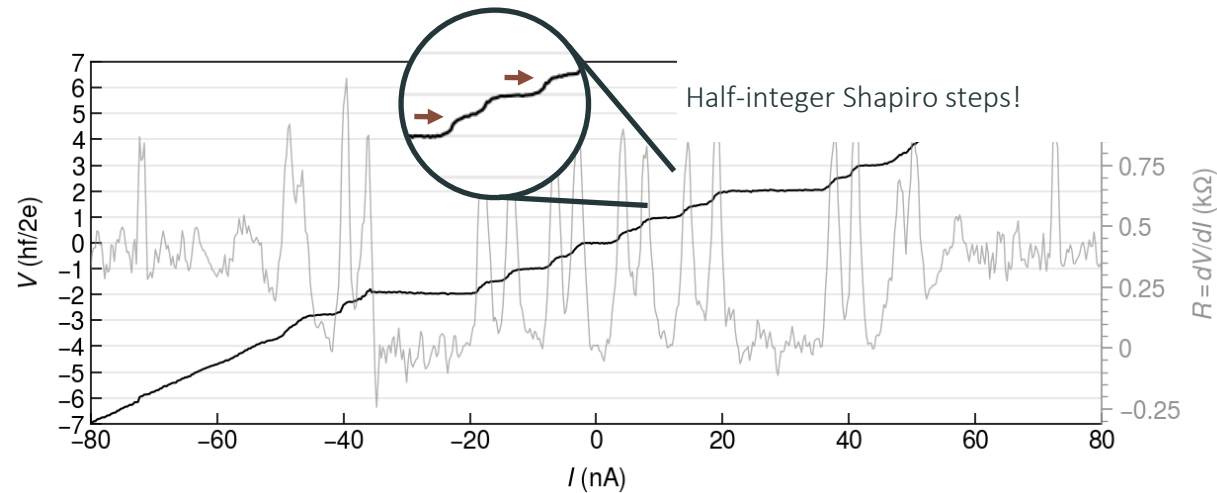
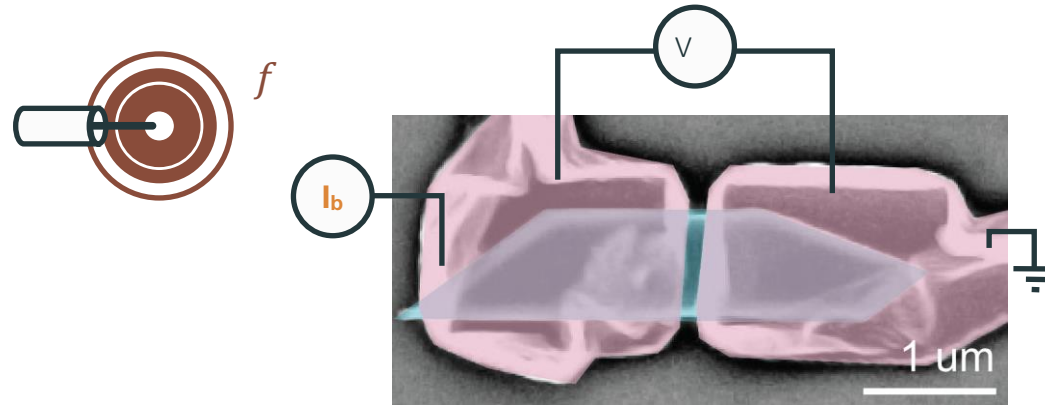
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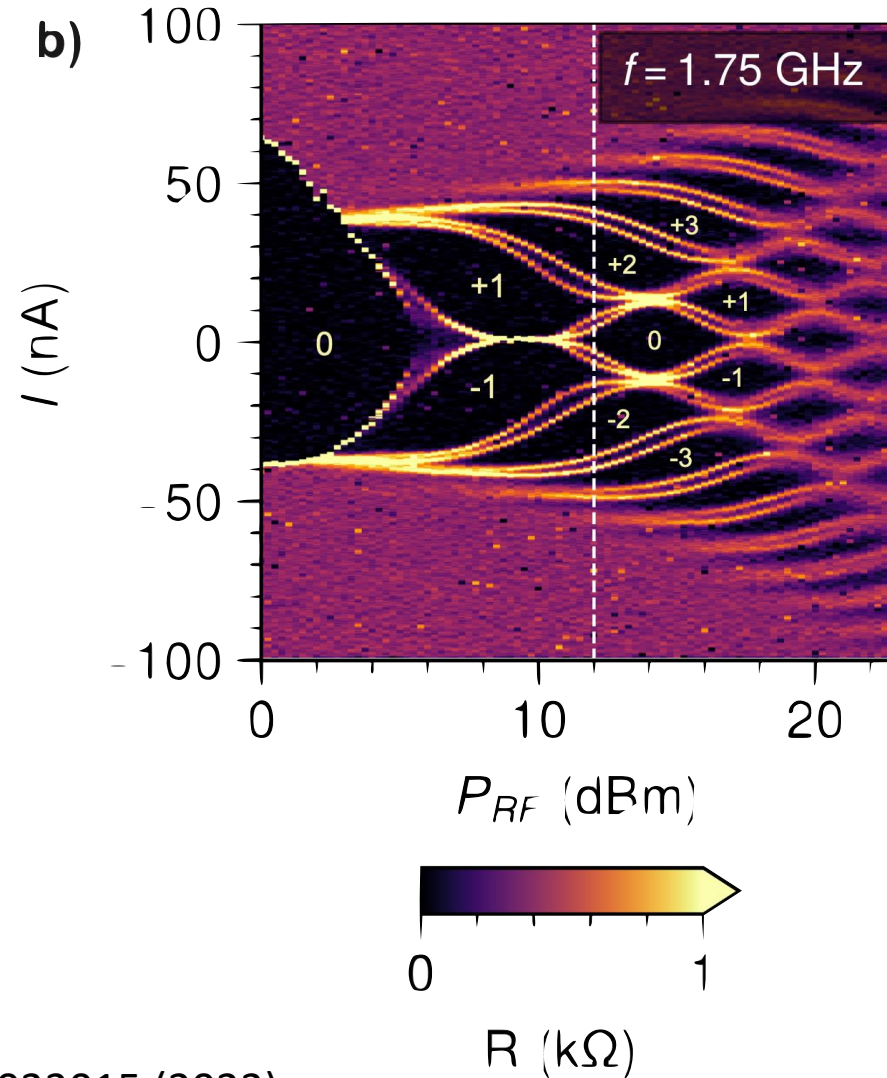
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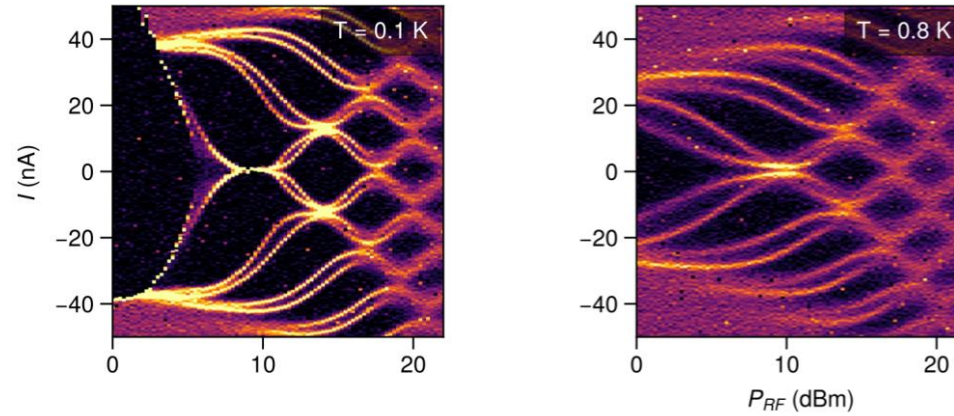
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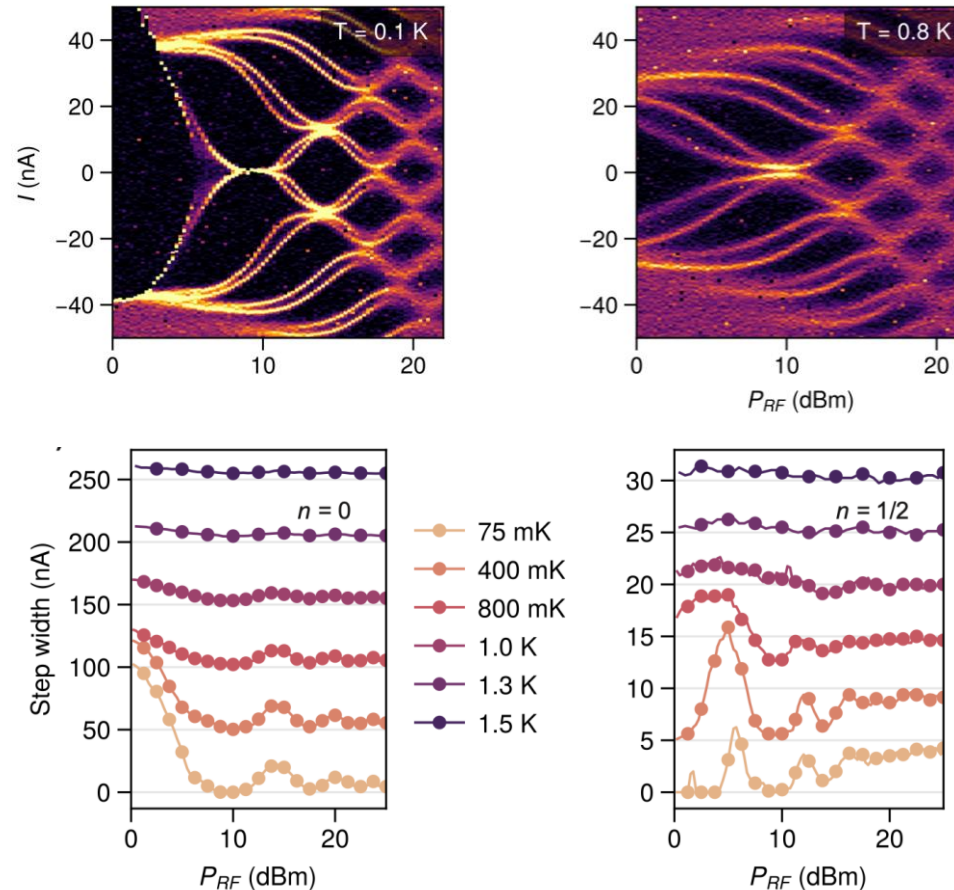
Half-integer Shapiro steps

A non-monotonic temperature dependence



Half-integer Shapiro steps

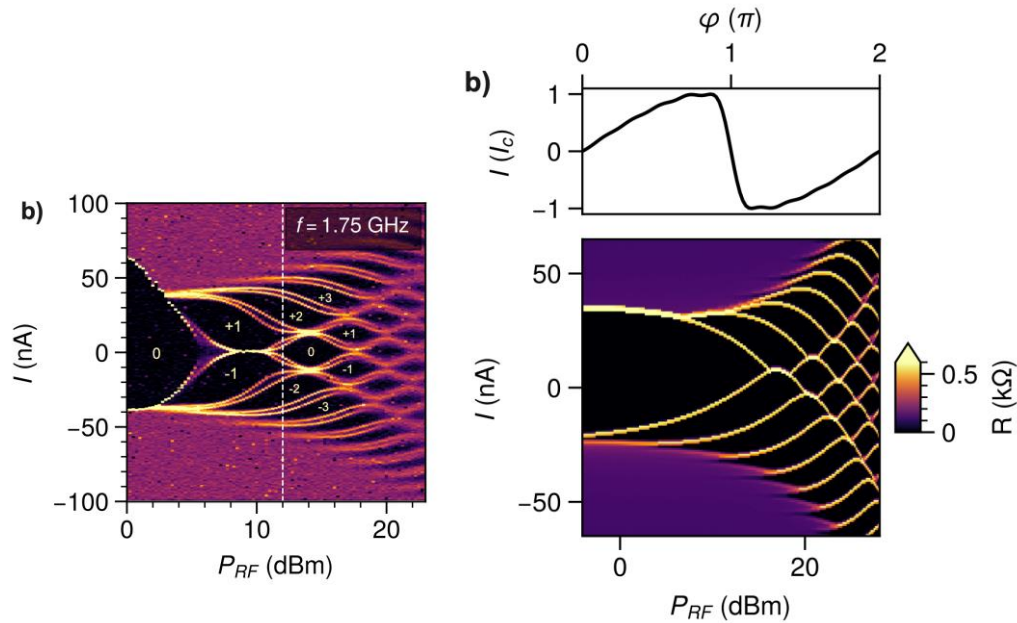
A non-monotonic temperature dependence



Half-integer Shapiro steps

How to have half-integer steps?

RCSJ simulations

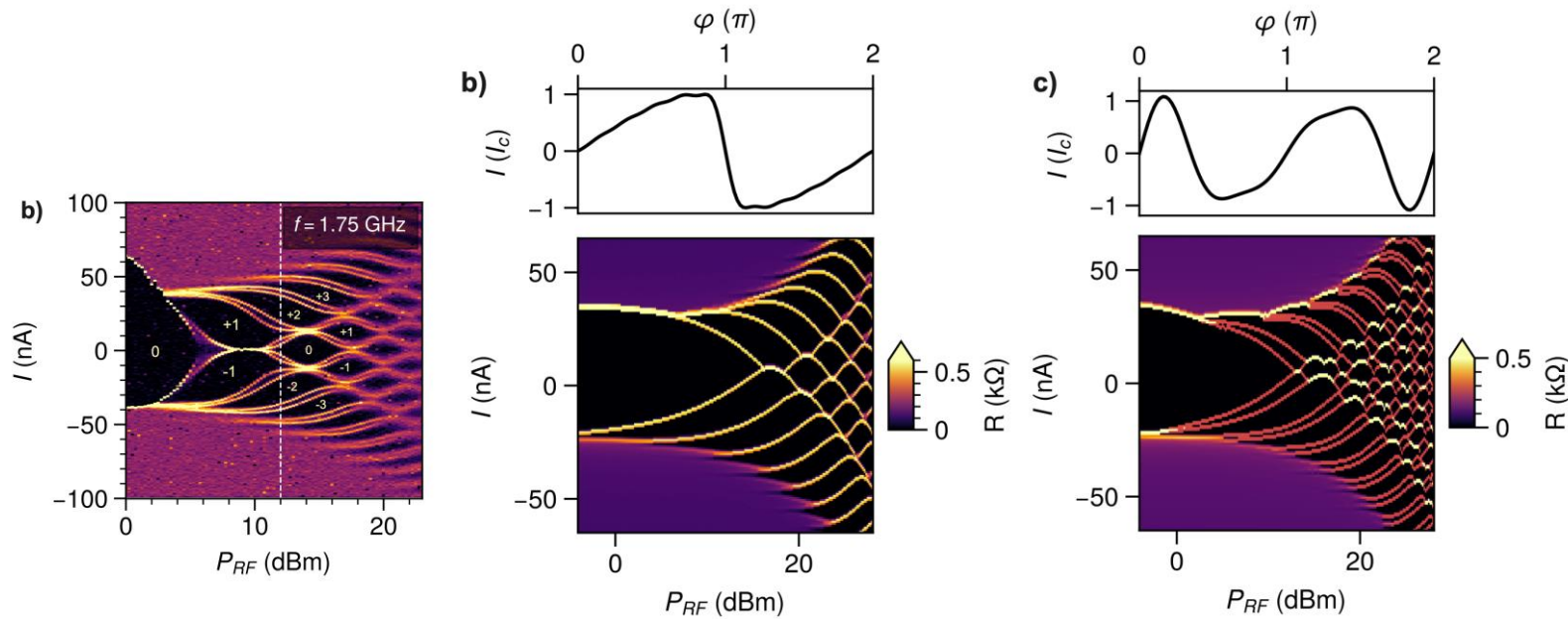


Half-integer Shapiro steps

How to have half-integer steps?

Need for a $\sin(2\varphi)$ CPR

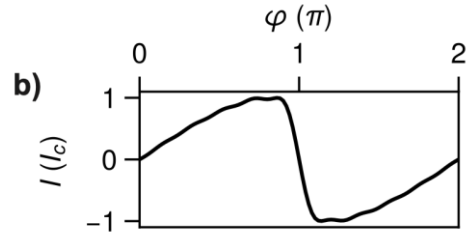
RCSJ simulations



Half-integer Shapiro steps

Potential mechanisms for $\sin(2\varphi)$

Higher harmonic in the equilibrium CPR

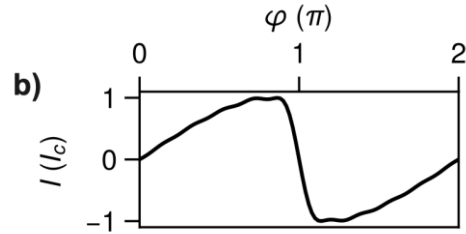


- ✓ Common given explanation
- ✗ Weaker half-steps
- ✗ Half-steps decrease with T

Half-integer Shapiro steps

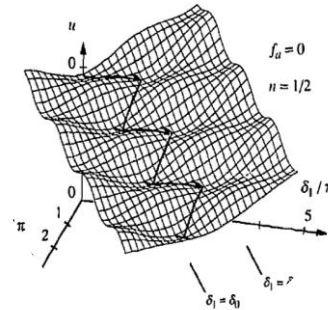
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SQUID-like



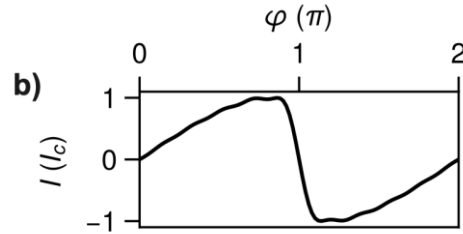
- ✓ Robust half-steps
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Physical basis for half-integral Shapiro steps in a dc SQUID. Physica C: Superconductivity 245.3-4 (1995)

Half-integer Shapiro steps

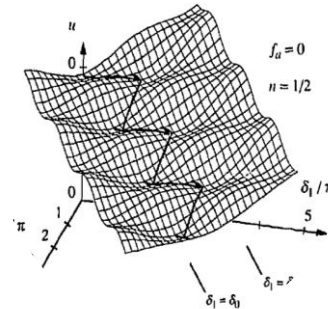
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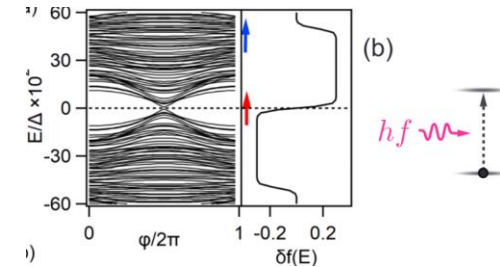
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Non-equilibrium excitations

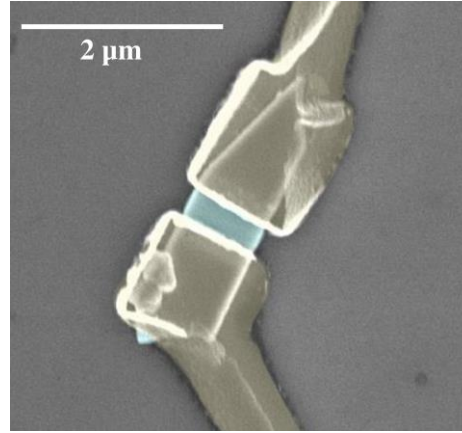


- ✓ $\sin(2\varphi)$ only when driving
- ✓ Half-steps non-monotonic in T
- ! Still some gaps with the theory

Physical basis for half-integral Shapiro steps in a dc SQUID. Physica C: Superconductivity 245.3-4 (1995)

Theory of microwave-assisted supercurrent in quantum point contacts. Physical review letters 105.11 (2010)
 Microwave photoassisted dissipation and supercurrent of a phase-biased graphene-superconductor ring. Physical Review Research 3.3 (2021) 

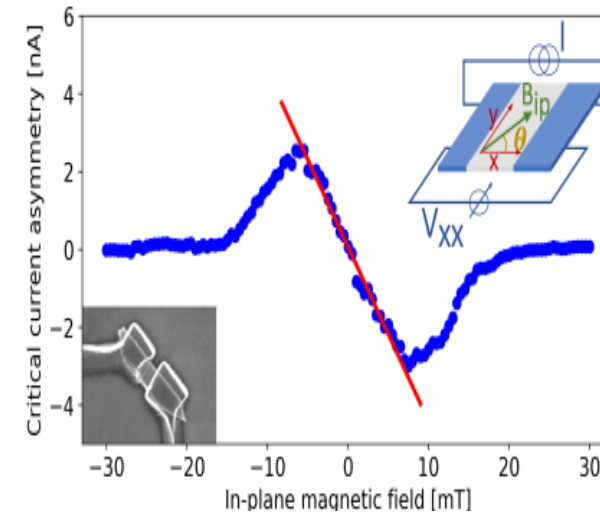
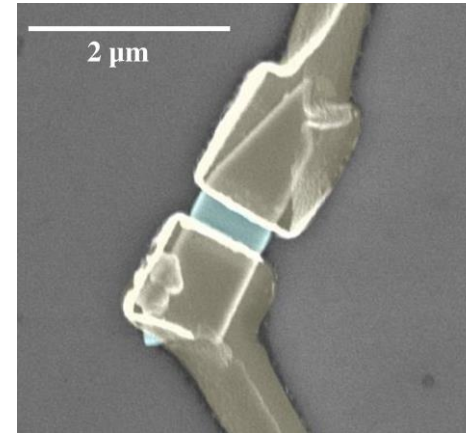
Summary



- InSb nanoflag-based Josephson junctions:
 - High-transparency of the interfaces
 - Ballistic transport
 - Gate-controlled supercurrent
- Josephson diode effect:
 - First observation of the JDE in InSb
 - Magnetic field-driven rectification
 - Relevance of Rashba SOC in the system
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 - Shapiro steps are still an open-topic in SNS devices
 - Controllable manipulation of bound states excitations (Andreev qubits)

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