Non-equilibrium microwave-induced supercurrents in highly transmissive InSb nanoflag Josephson junctions
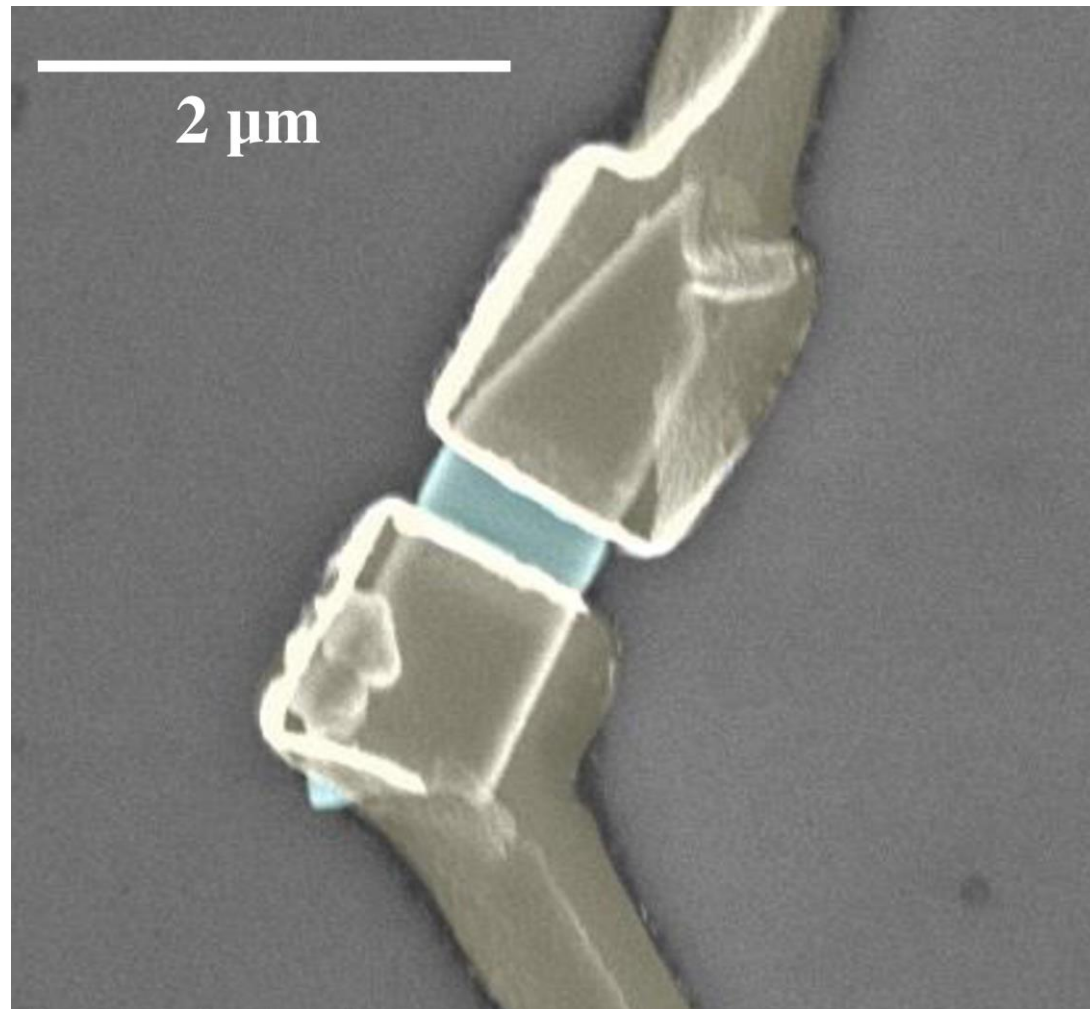
Consortium Meeting

Stefan Heun (CNR-Pisa)
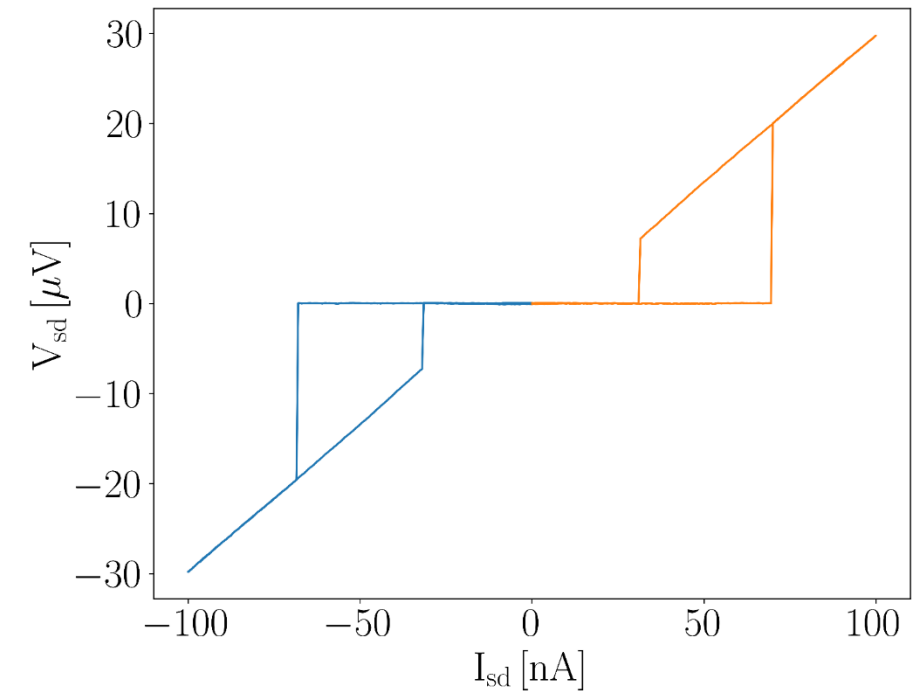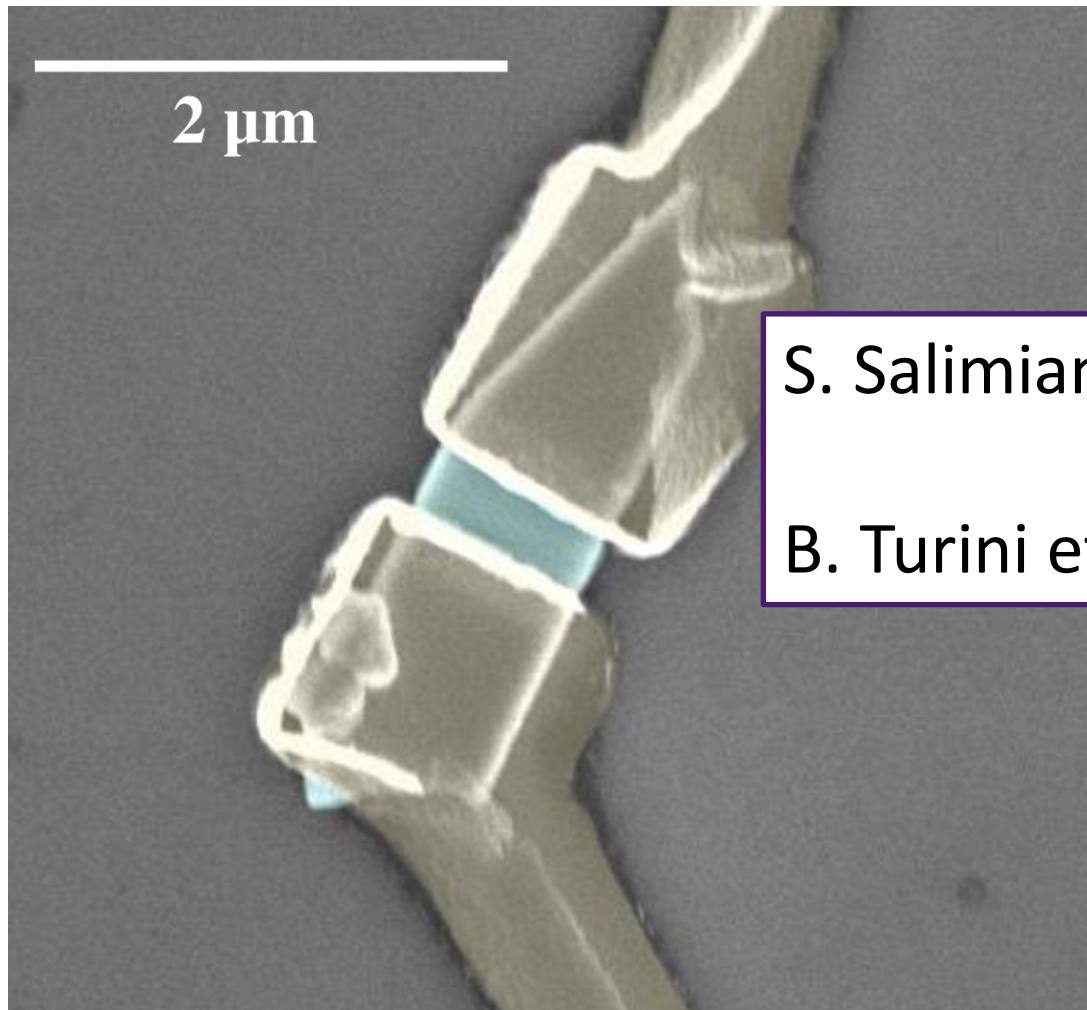
2-3 March 2023

Nb/Ti-InSb Nanoflag-based JJs

10 nm Ti/150 nm Nb
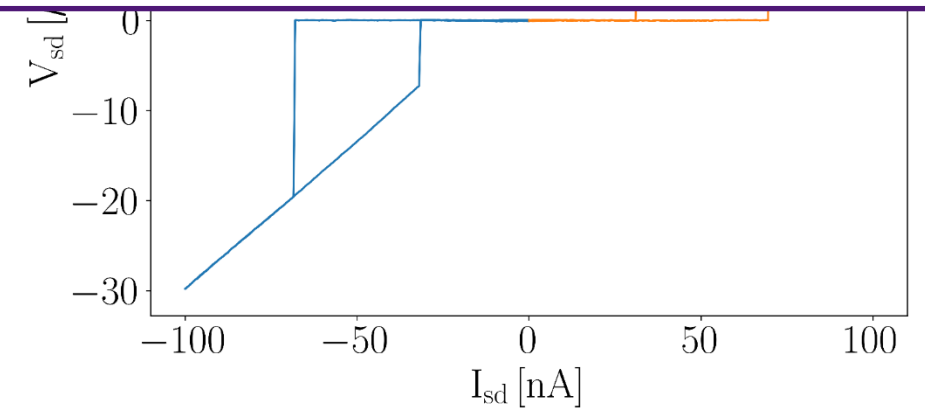Substrate: Si/SiO$_2$
L = 200 nm, W = 700 nm

AndQC

Nb/Ti-InSb Nanoflag-based JJs

10 nm Ti/150 nm Nb
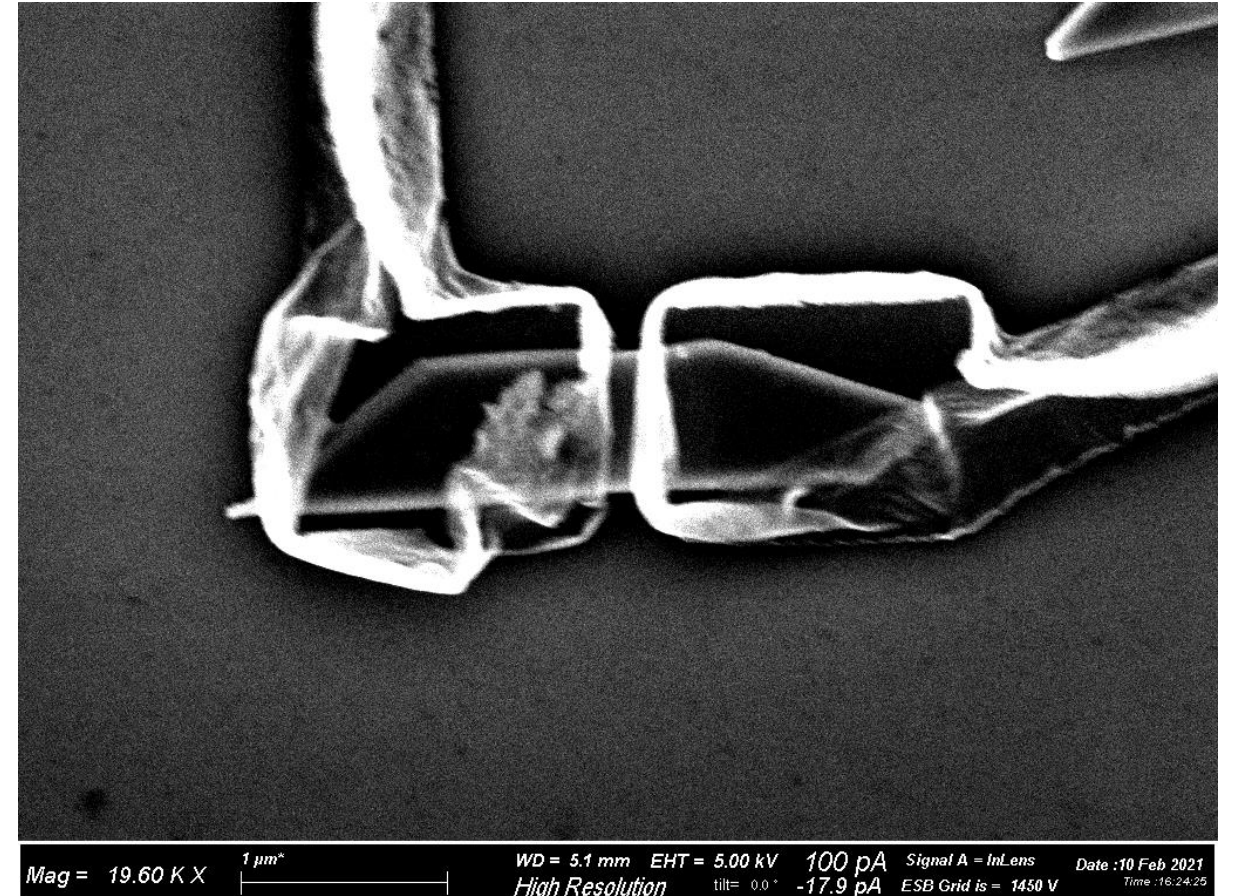Substrate: Si/SiO$_2$
L = 200 nm, W = 700 nm

S. Salimian et al., Appl. Phys. Lett. 119, 214004 (2021).

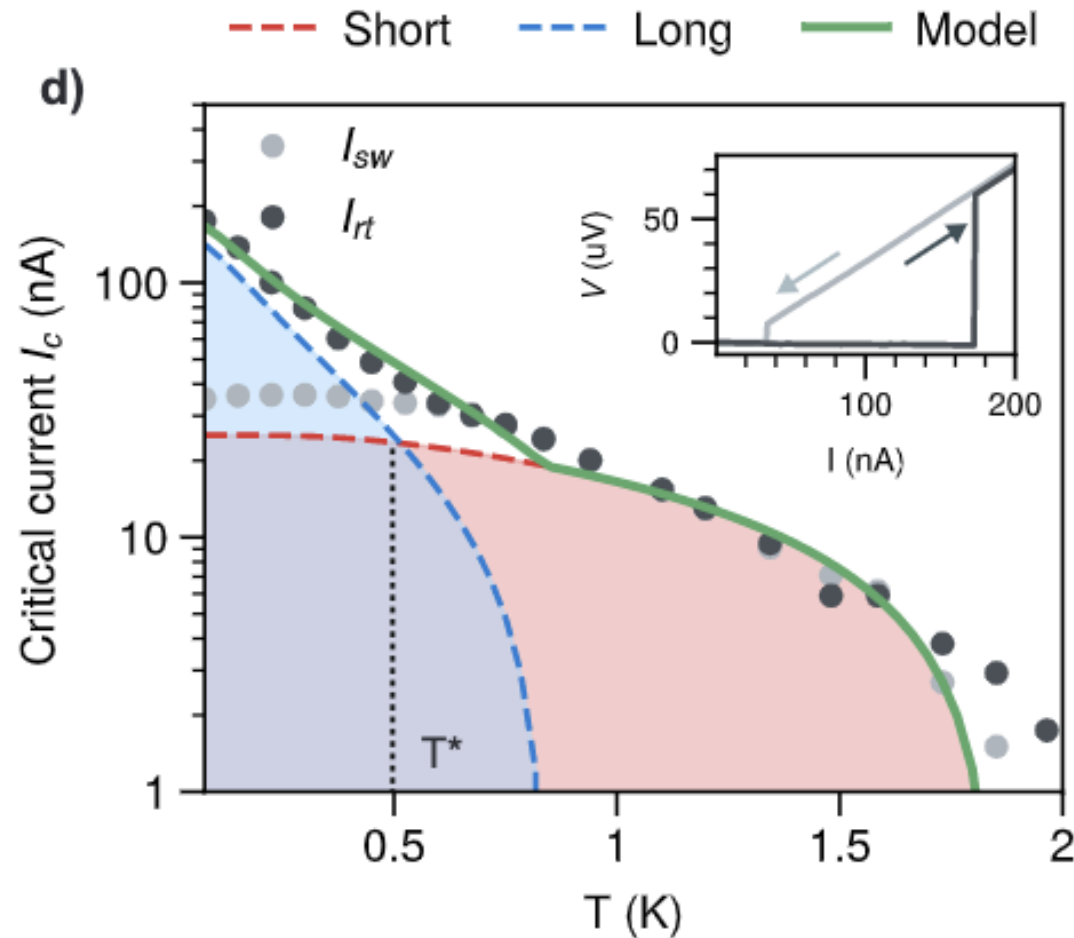B. Turini et al., Nano Lett. 22, 8502–8508 (2022).

Chip SC 18 device I6 1-3

- InSb nanoflag (3.35 μm x 650 nm)

- 150 nm-thick Nb contacts

- Channel length L = 80 nm
- Mean free path 500 nm
- Coherence length 720 nm
- Short ballistic junction

Mag = 19.60 K X　　1 µm*　　WD = 5.1 mm　EHT = 5.00 kV　100 pA　Signal A = InLens　Date :10 Feb 2021
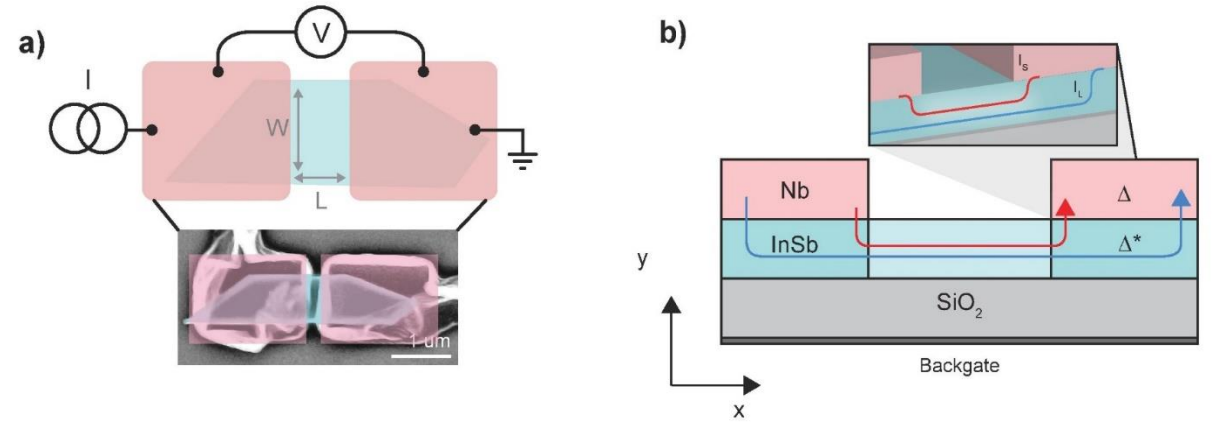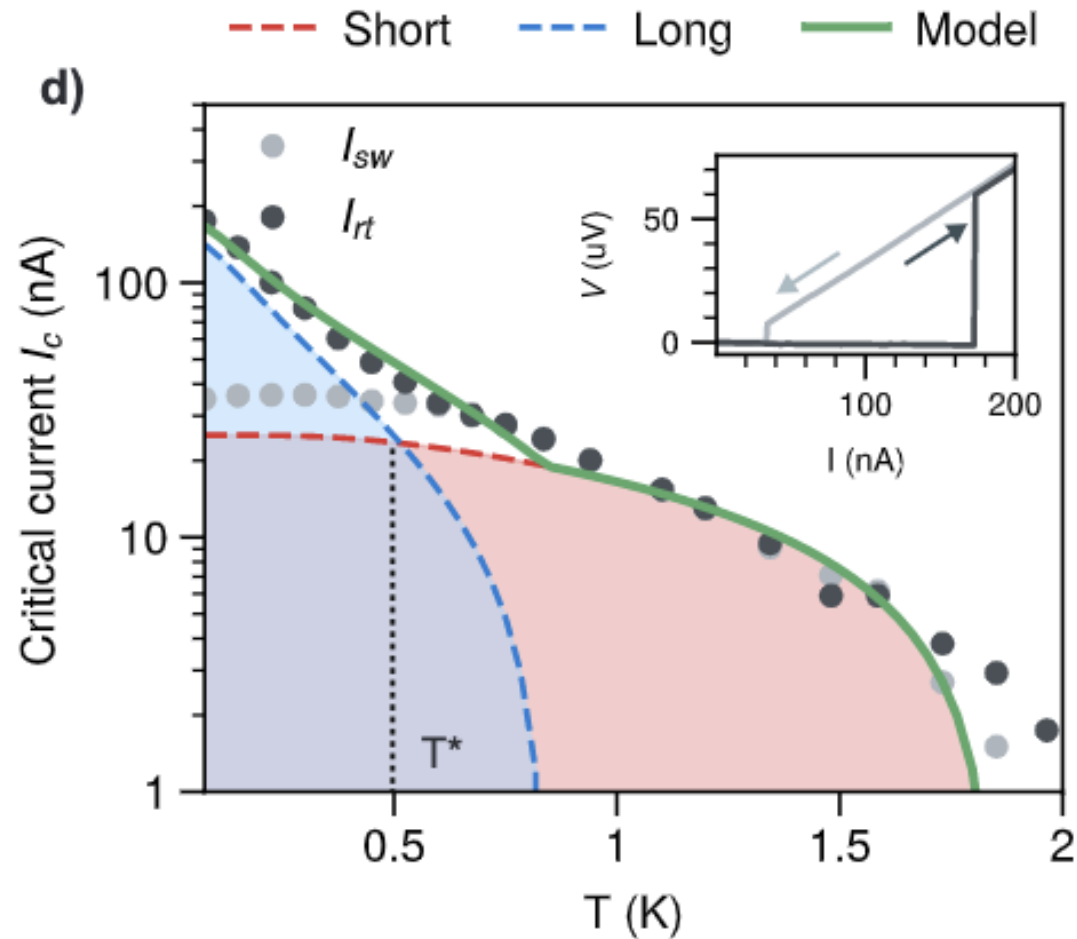High Resolution　　tilt= 0.0 °　-17.9 pA　ESB Grid is = 1450 V　Time :16:24:25

T-dependence of critical current

- I_{sw} = 170 nA
- I_{rt} = 30 nA

- $T < T^*$: exponential increase in I_{sw} with decreasing T (long junction)
- Fit: E_{Th} = 20 μeV, path length 3.5 μm

- $T > T^*$: I_{sw} follows predictions for short junction model (τ = 0.93)

AndQC

T-dependence of critical current

- T < T*: exponential increase in I_{sw} with decreasing T (long junction)
- Fit: E_{Th} = 20 μeV, path length 3.5 μm

- T > T*: I_{sw} follows predictions for short junction model (τ = 0.93)
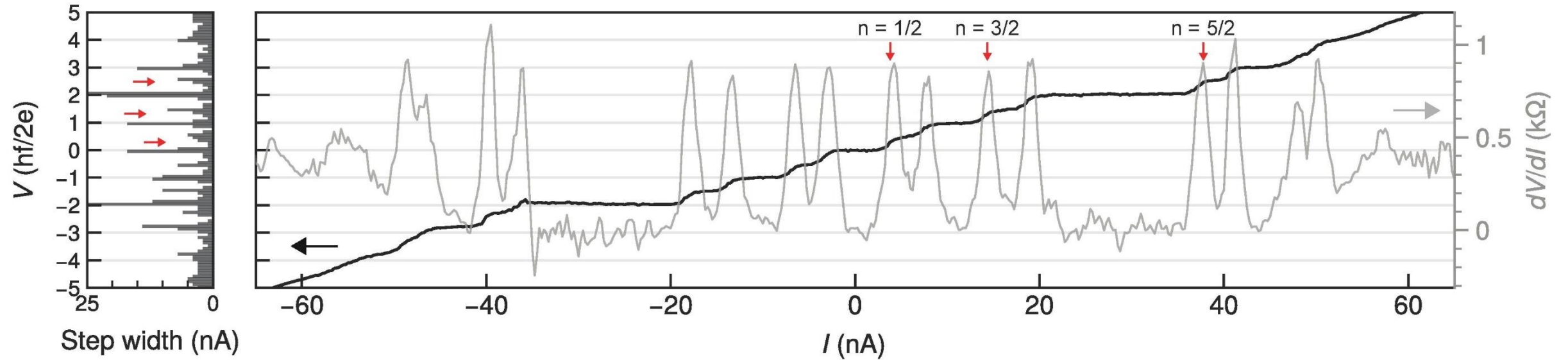
Magneto-transport
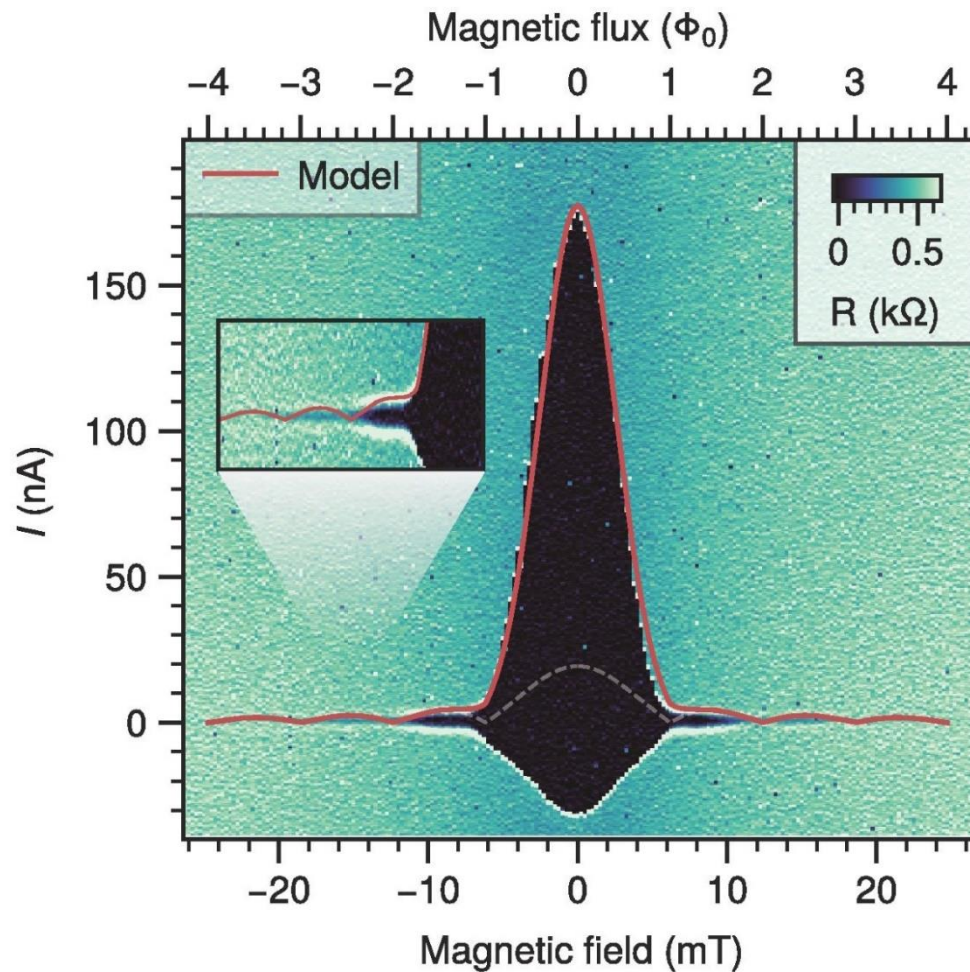
- **Unconventional Fraunhofer pattern**
- **Well described by superposition of**
  - Conventional Fraunhofer pattern (short junction)
  - Monotonic quasi-Gaussian decay (long junction)
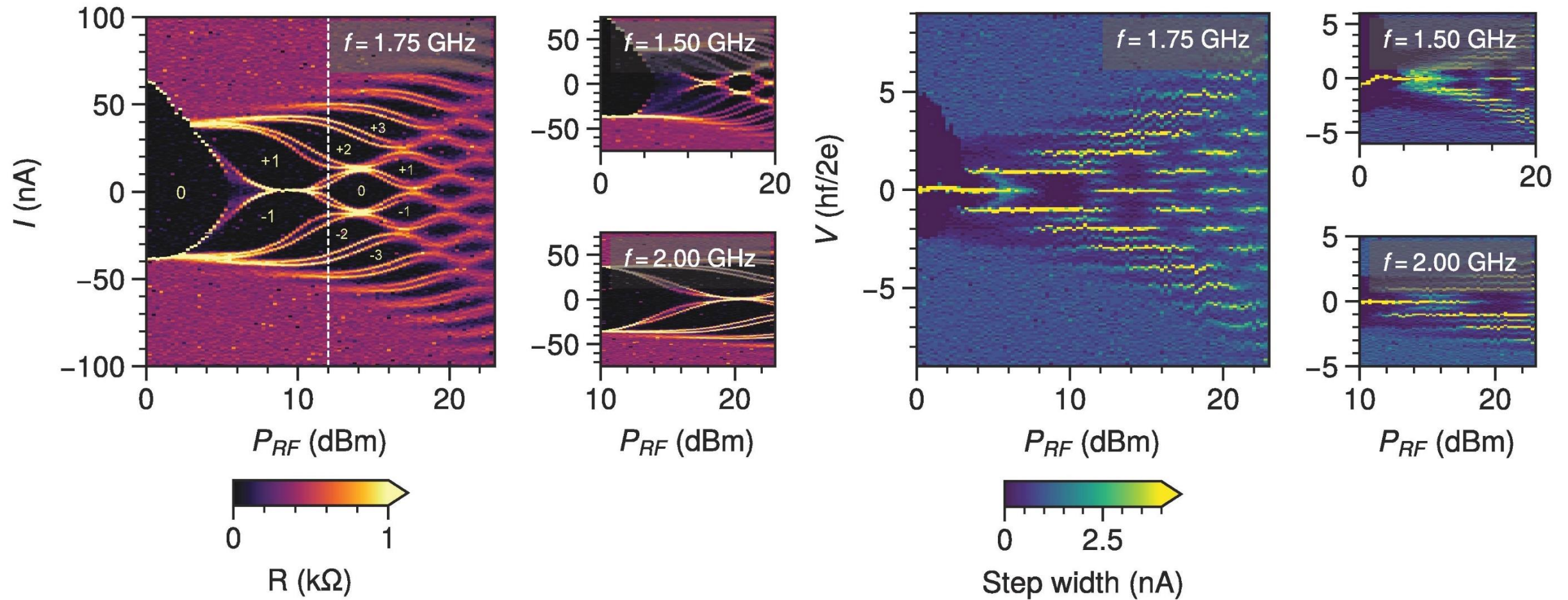
Temperature-dependence of the magnetoresistance
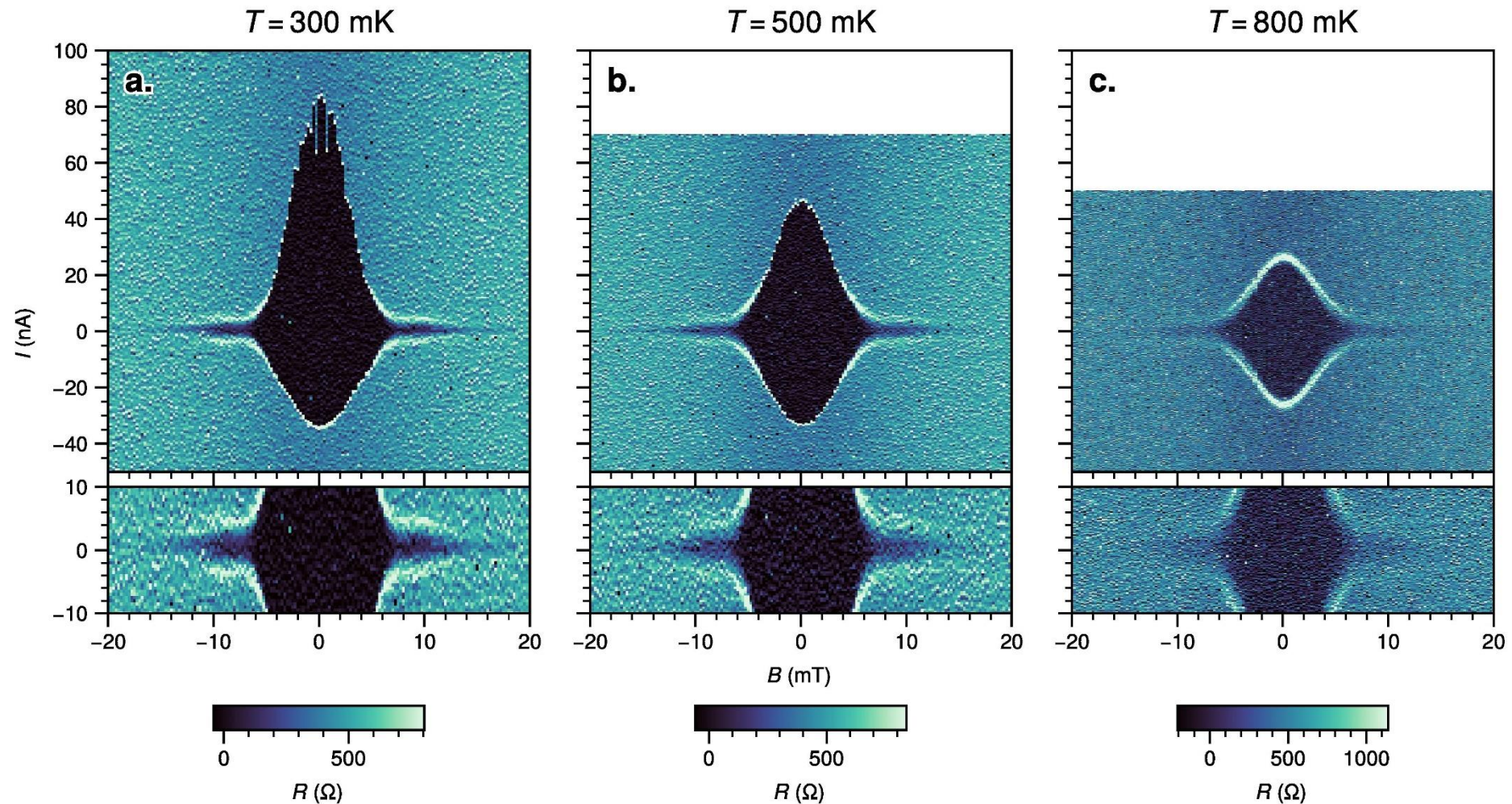
Shapiro-steps

$$V_n = nhf / 2e$$

(f = 1.75 GHz, P_{rf} = 12 dBm)

AndQC

Shapiro steps

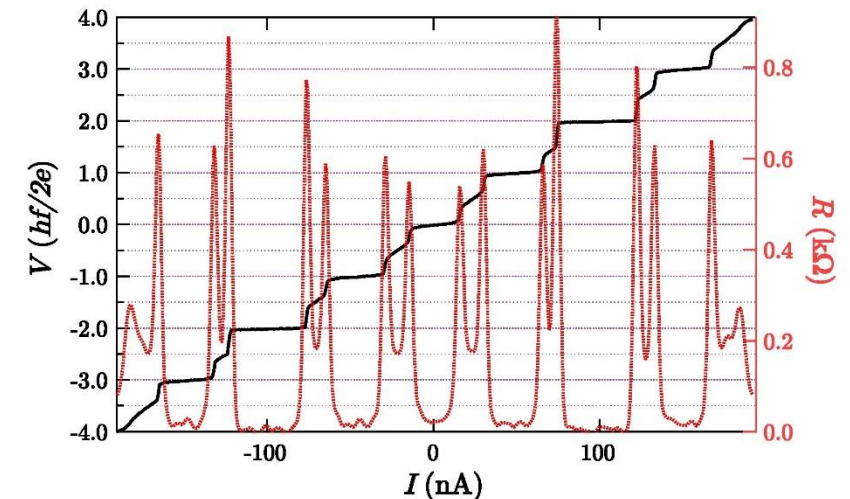# Half-integer Shapiro steps (equilibrium)

- **Observed in (among others)**
  - Junctions incorporating ferromagnetic layers
  - More complex circuit networks, such as junction arrays or SQUIDs
  - Non-sinusoidal CPR in highly transparent SNS

Evidence of half-integer Shapiro steps originated from nonsinusoidal current phase relation in a short ballistic InAs nanowire Josephson junction

Kento Ueda[1,*] Sadashige Matsuo[2,3,†] Hiroshi Kamata[4] Yosuke Sato,[1] Yuusuke Takeshige[1] Kan Li,[5] Lars Samuelson,[6] Hongqi Xu[5,6,7,‡] and Seigo Tarucha[3,§]

We report on half-integer Shapiro steps observed in a gate-tunable short ballistic InAs nanowire Josephson junction. We observed the Shapiro steps of the short ballistic InAs nanowire Josephson junction and found the half-integer steps in addition to the conventional integer steps. In this Josephson junction device the junction transmission can be varied with gate voltage. From measurements of the gate voltage and temperature dependences of the Shapiro steps, the origin of half-integer steps is assigned to the skewness of the current phase relation in the short ballistic Josephson junctions. These results will contribute to establish and control the superconductivity physics in the short ballistic semiconductor nanowires.
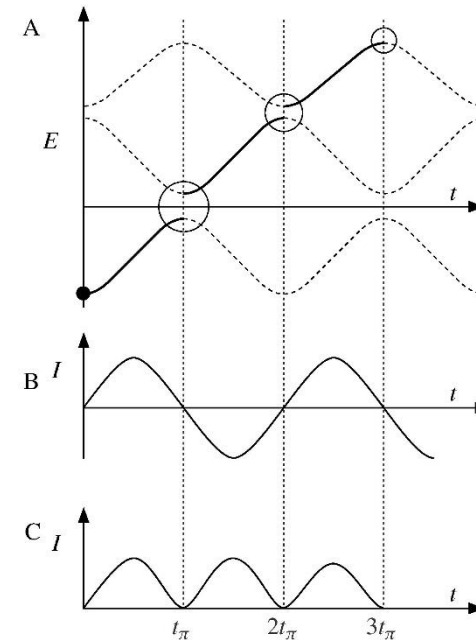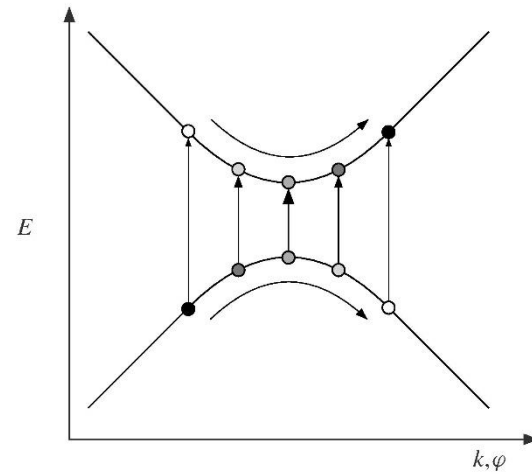
AndQC

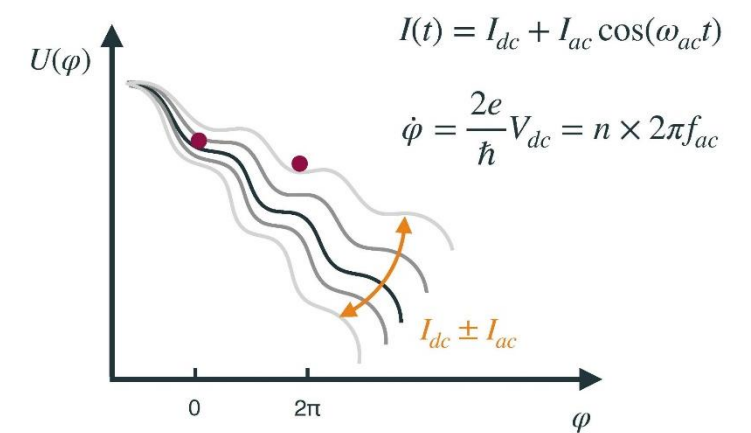# Half-integer Shapiro steps (non-equilibrium)

- Non-equilibrium occupation probability of Andreev Bound States
  - Strong 2φ-periodic oscillations at twice the Josephson frequency
  - Giving rise to half-integer Shapiro-steps
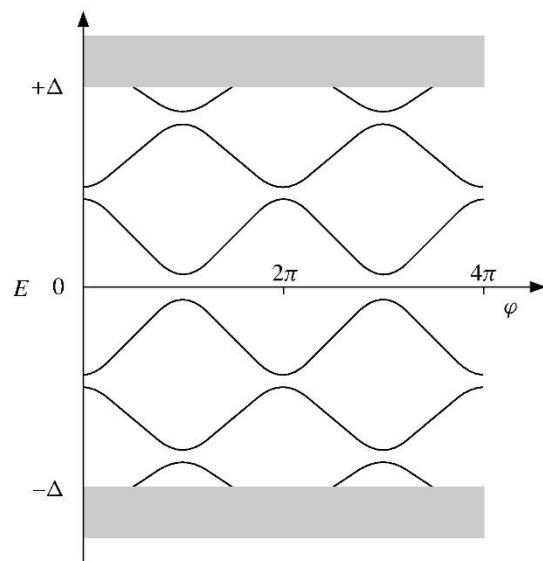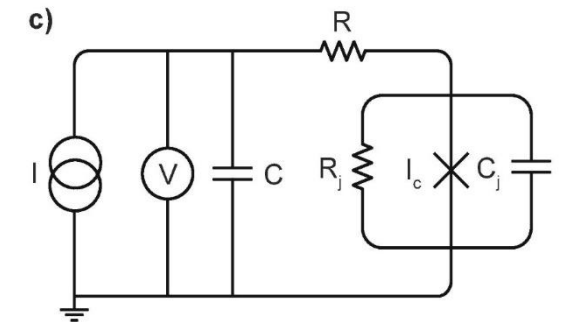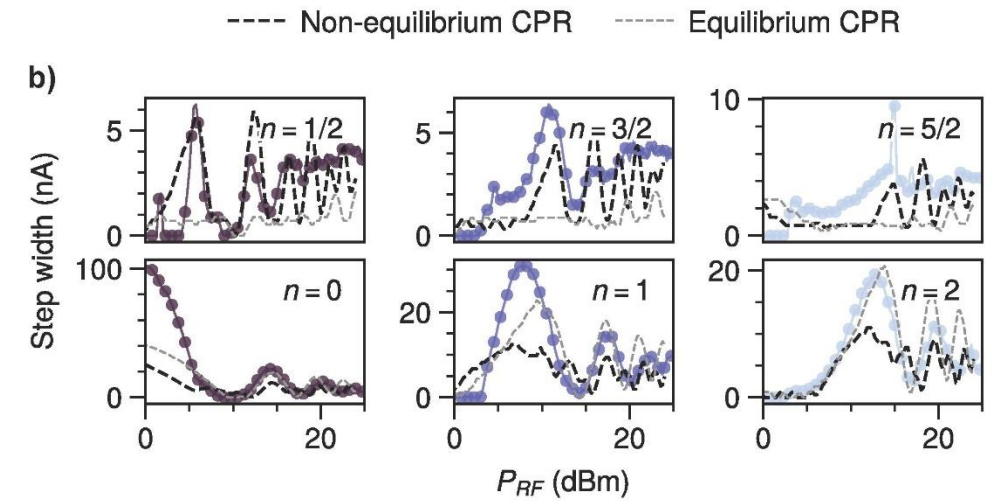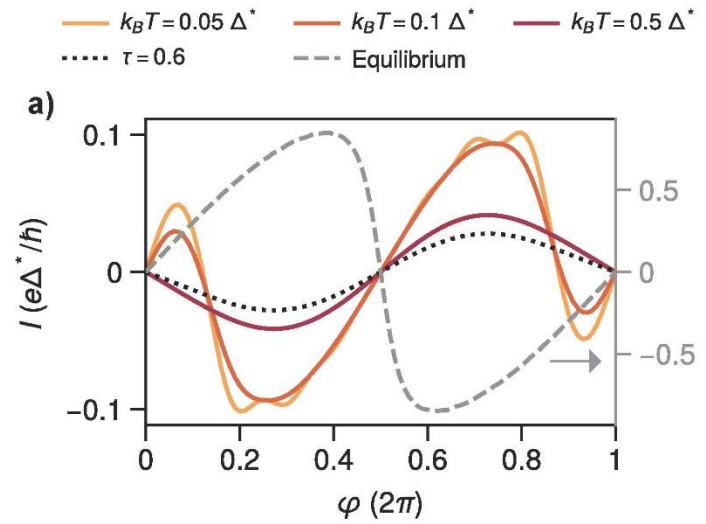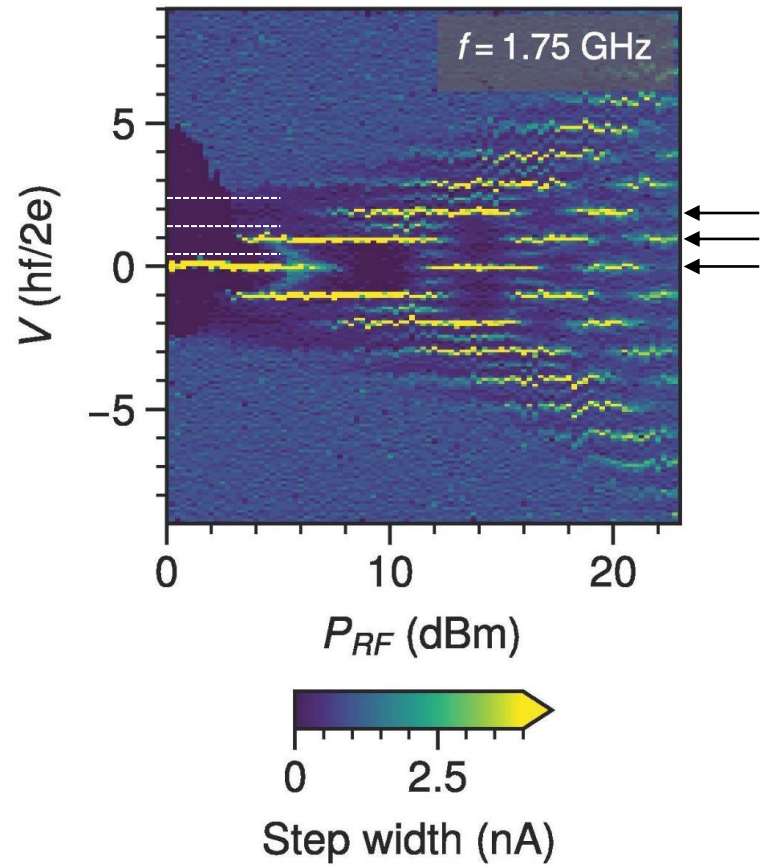

Schematic Andreev Bands

$$I(t) = I_{dc} + I_{ac}\cos(\omega_{ac}t)$$

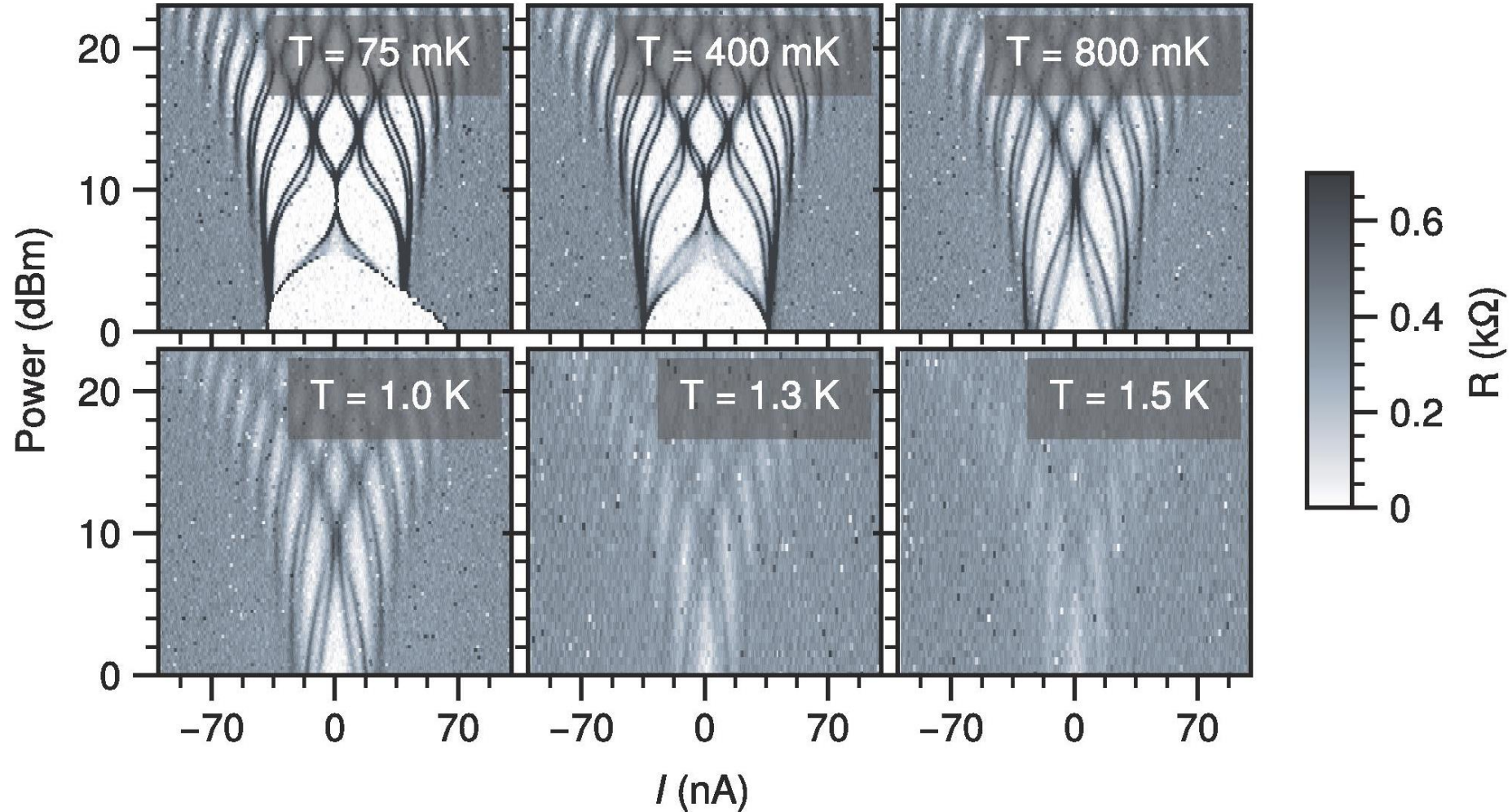$$\dot{\varphi} = \frac{2e}{\hbar}V_{dc} = n \times 2\pi f_{ac}$$

$I_{dc} \pm I_{ac}$

H. Kroemer, Superlattices and Microstructures 25 (1999) 877.

Josephson frequency $\omega_J = \dfrac{d\varphi}{dt} = \dfrac{2eV}{\hbar}$

$$I = \frac{2e}{\hbar} \cdot \frac{dE}{d\varphi}$$

AndQC

Shapiro steps
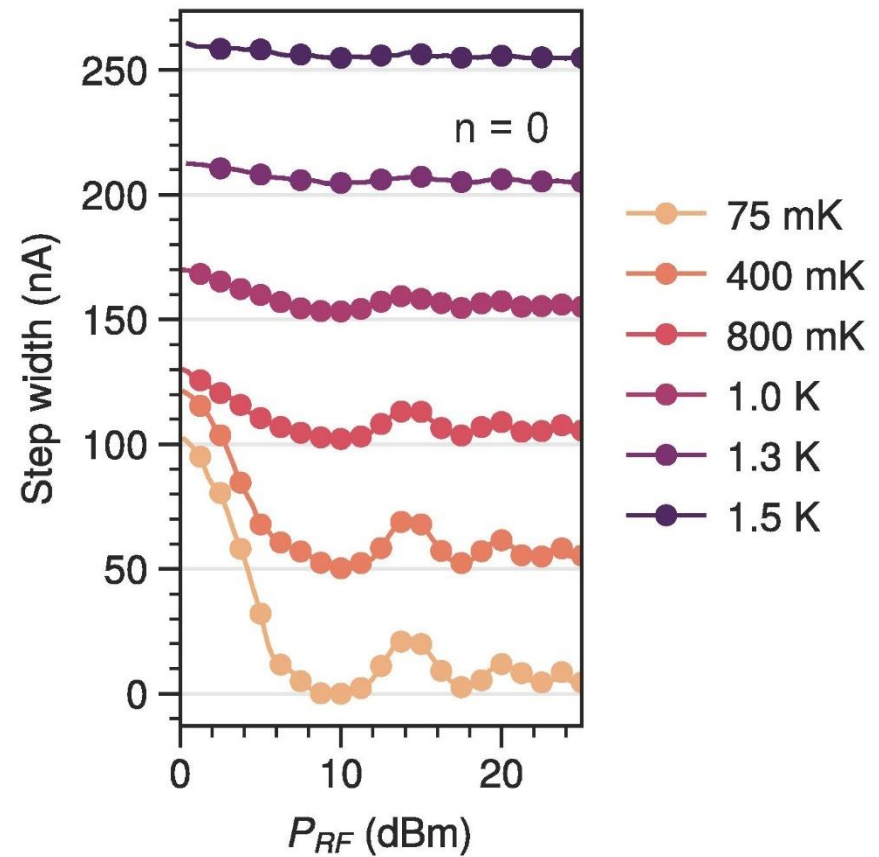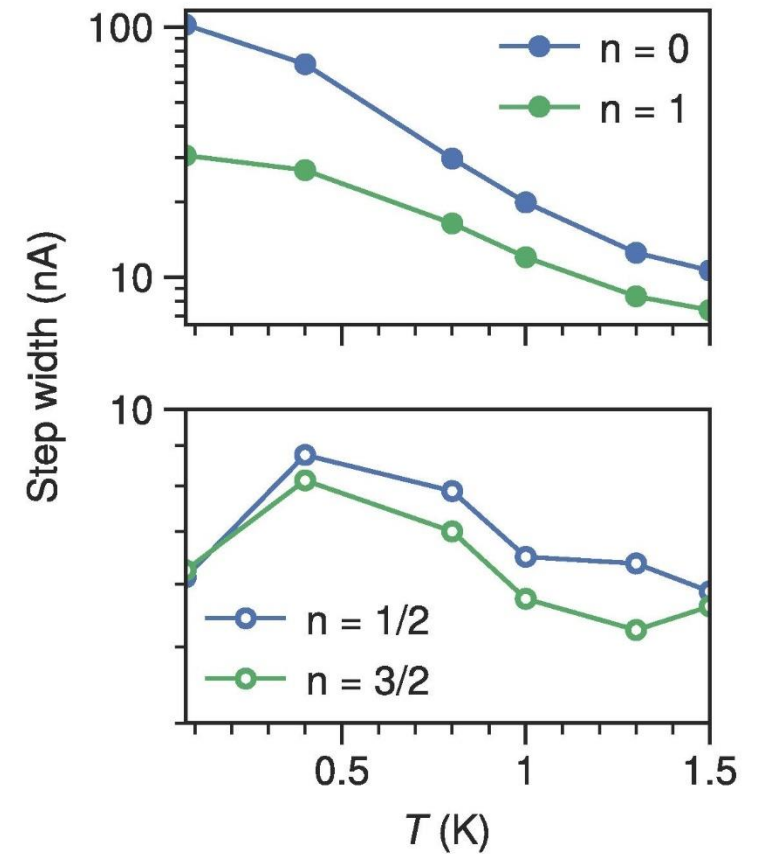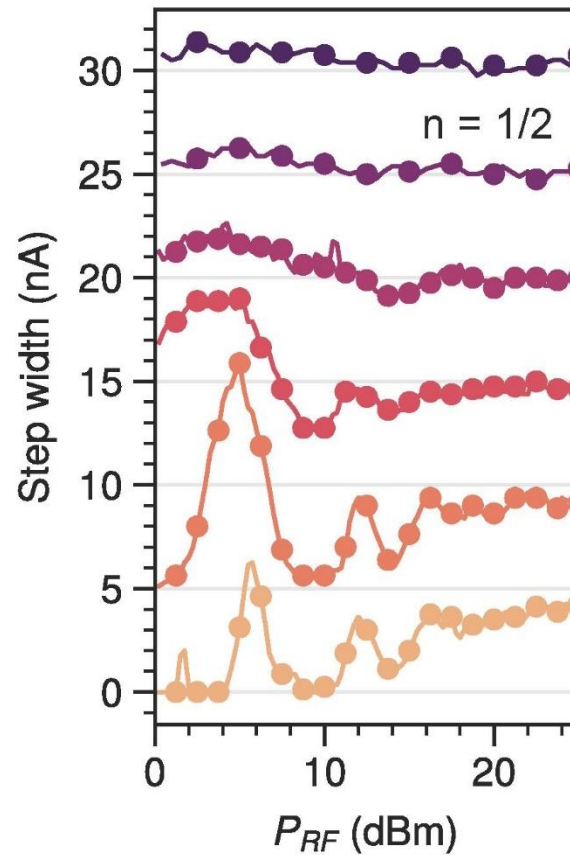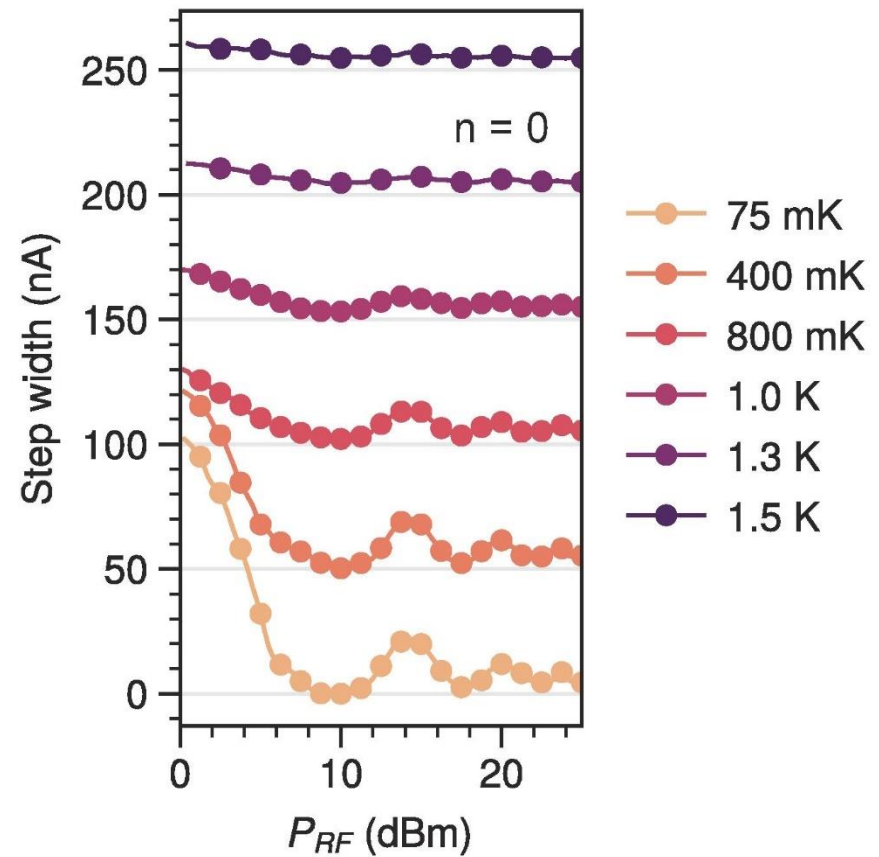
RCSJ model

Temperature-dependence of Shapiro steps

AndQC

Temperature-dependence of Shapiro steps

Temperature-dependence of Shapiro steps

AndQC
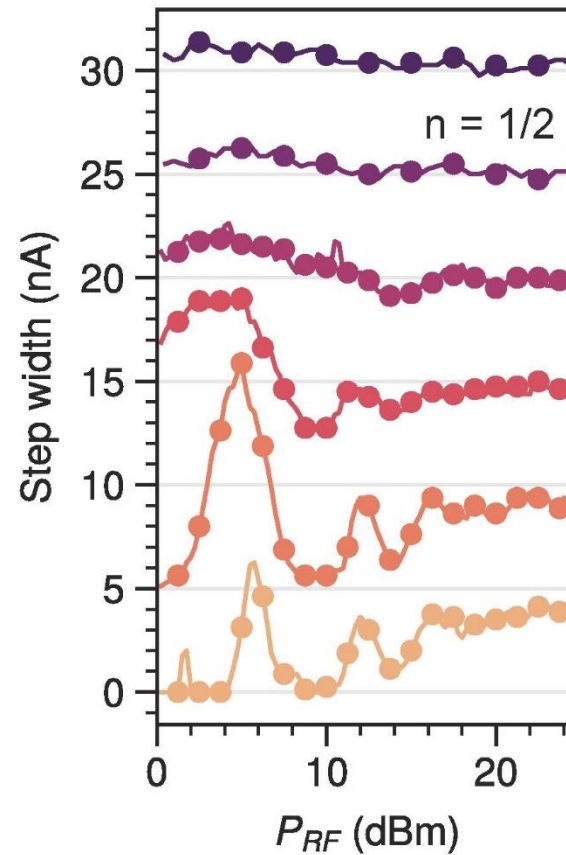
Conclusions

- The high transparency of the Nb-InSb interfaces allows the investigation of unexplored transport regimes (with parallel short and long conducting channels).

- Under microwave irradiation, non-equilibrium supercurrents are excited at twice the Josephson frequency, which results in half-integer Shapiro-steps.

AndQC