University of Basel

Journal Club

Dissipation-driven phase transition in a Josephson junction

Kristupas Razas, 30.01.2026

Agenda.

1	Concept
2	Overview of past work
3	Experimental results of the chosen paper
4	Conclusion and Discussion

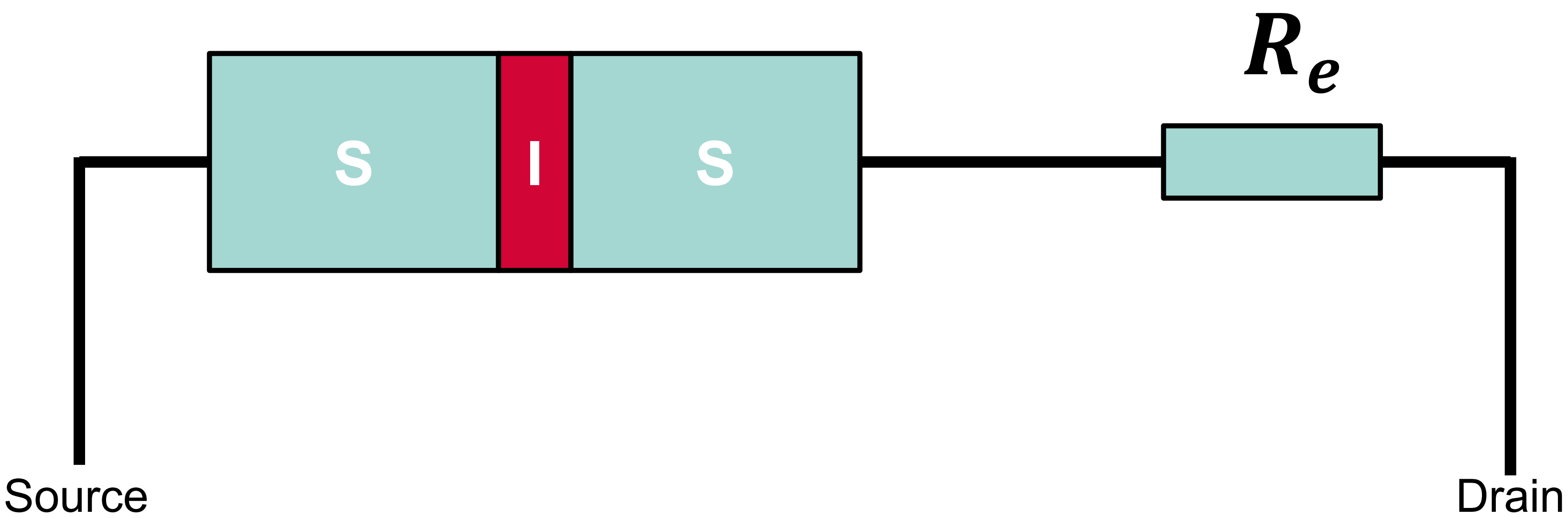
Main Reference

Revisiting dissipation-driven phase transition in a Josephson junction

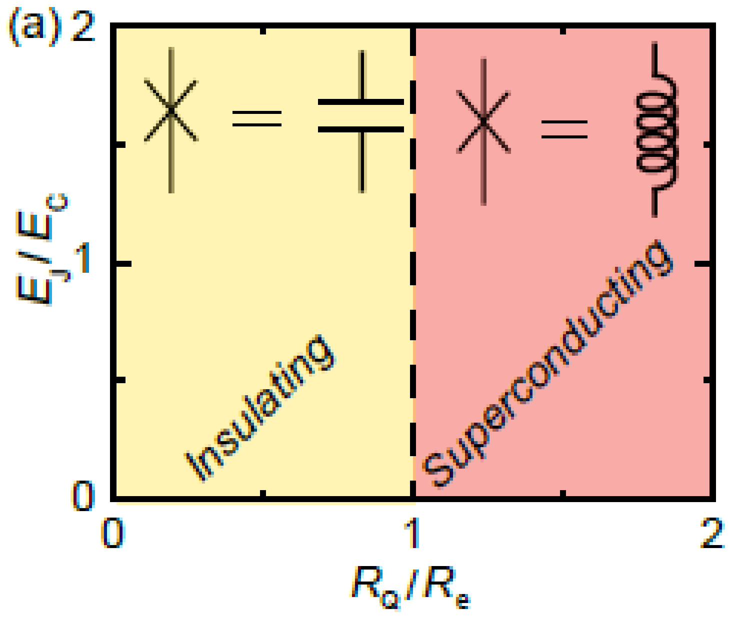
Diego Subero,[1,*] Yu-Cheng-Chang,[1] Miguel Monteiro,[1] Ze-Yan Chen,[1] and Jukka P. Pekola[1]
[1]*PICO Group, QTF Centre of Excellence, Department of Applied Physics, Aalto University School of Science, P.O. Box 13500, 0076 Aalto, Finland*

Original Idea

[1] A. Schmid, Diffusion and localization in a dissipative quantum system, Phys. Rev. Lett **51**, 1506 (1983).
[2] S. Bulgadaev, Phase diagram of a dissipative quantum system, JETP Lett **39**, 264 (1984).

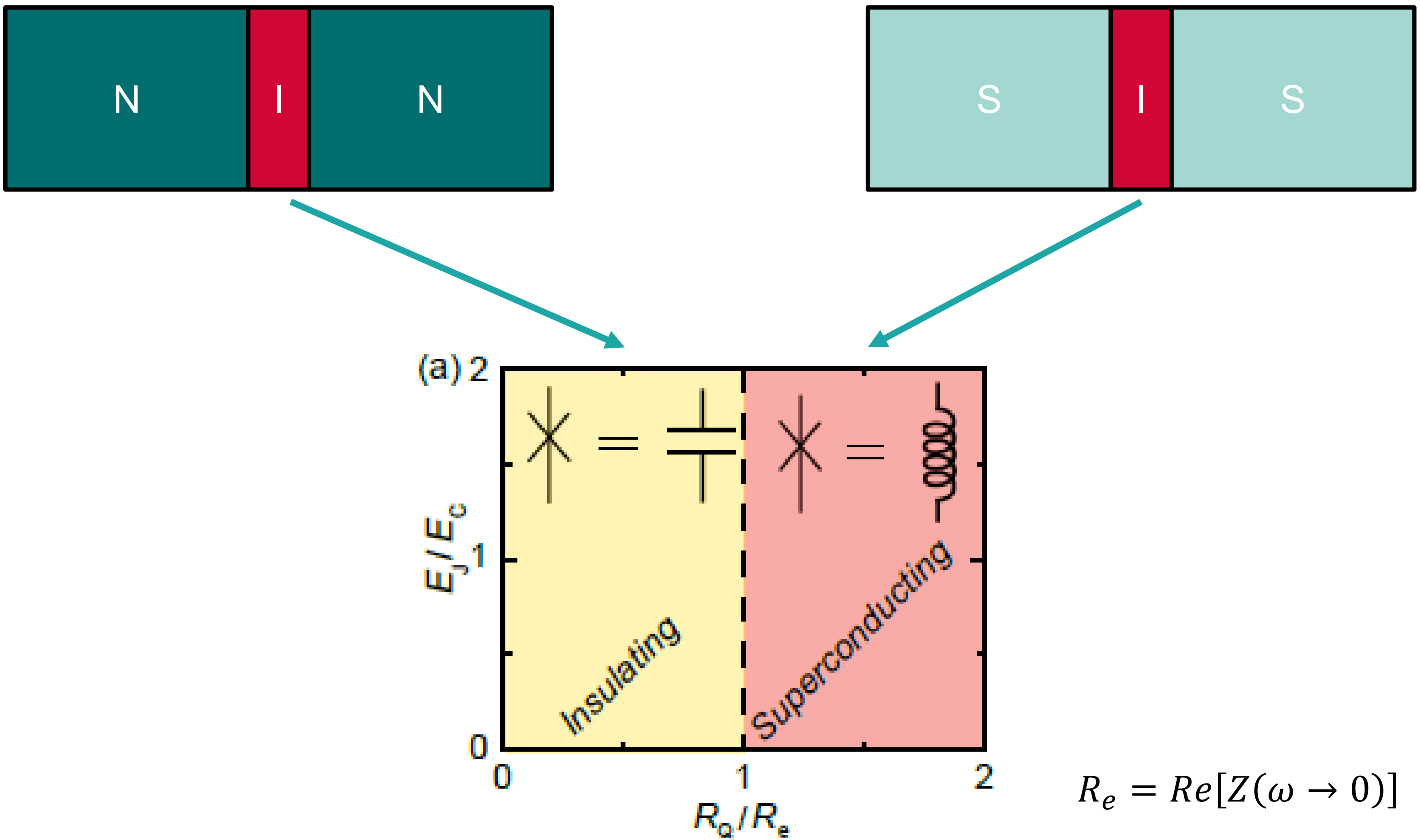


Predicted Phase Transition at T =0



$R_e = Re[Z(\omega \rightarrow 0)]$

Predicted Phase Transition at T =0



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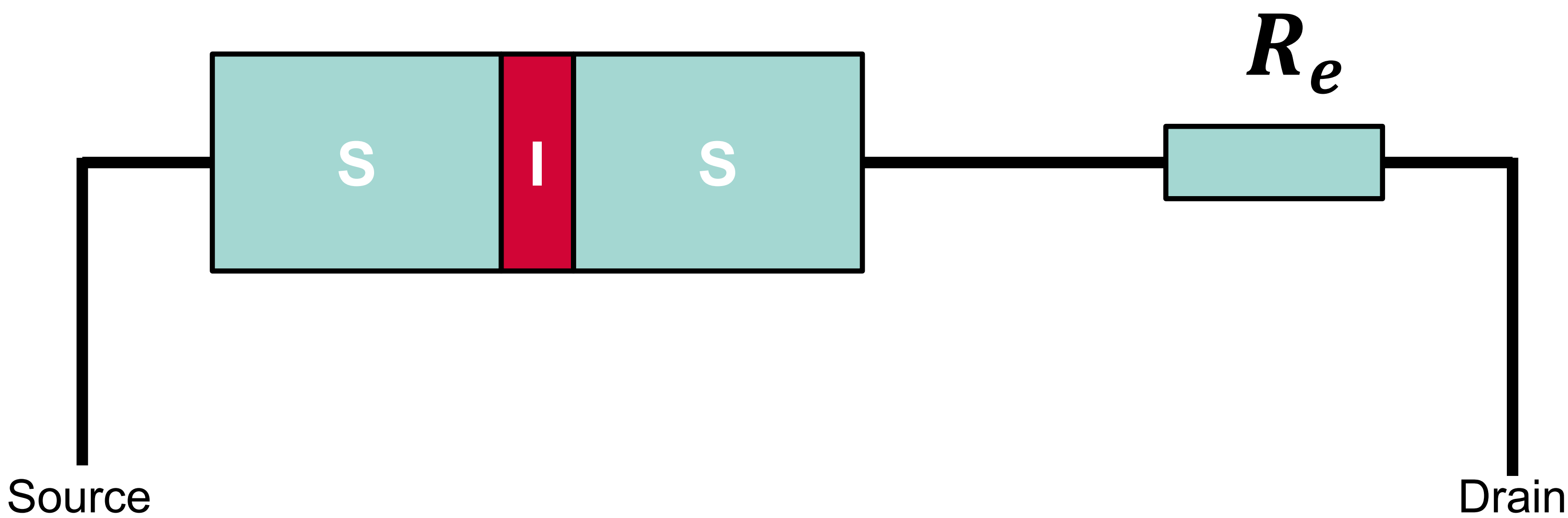
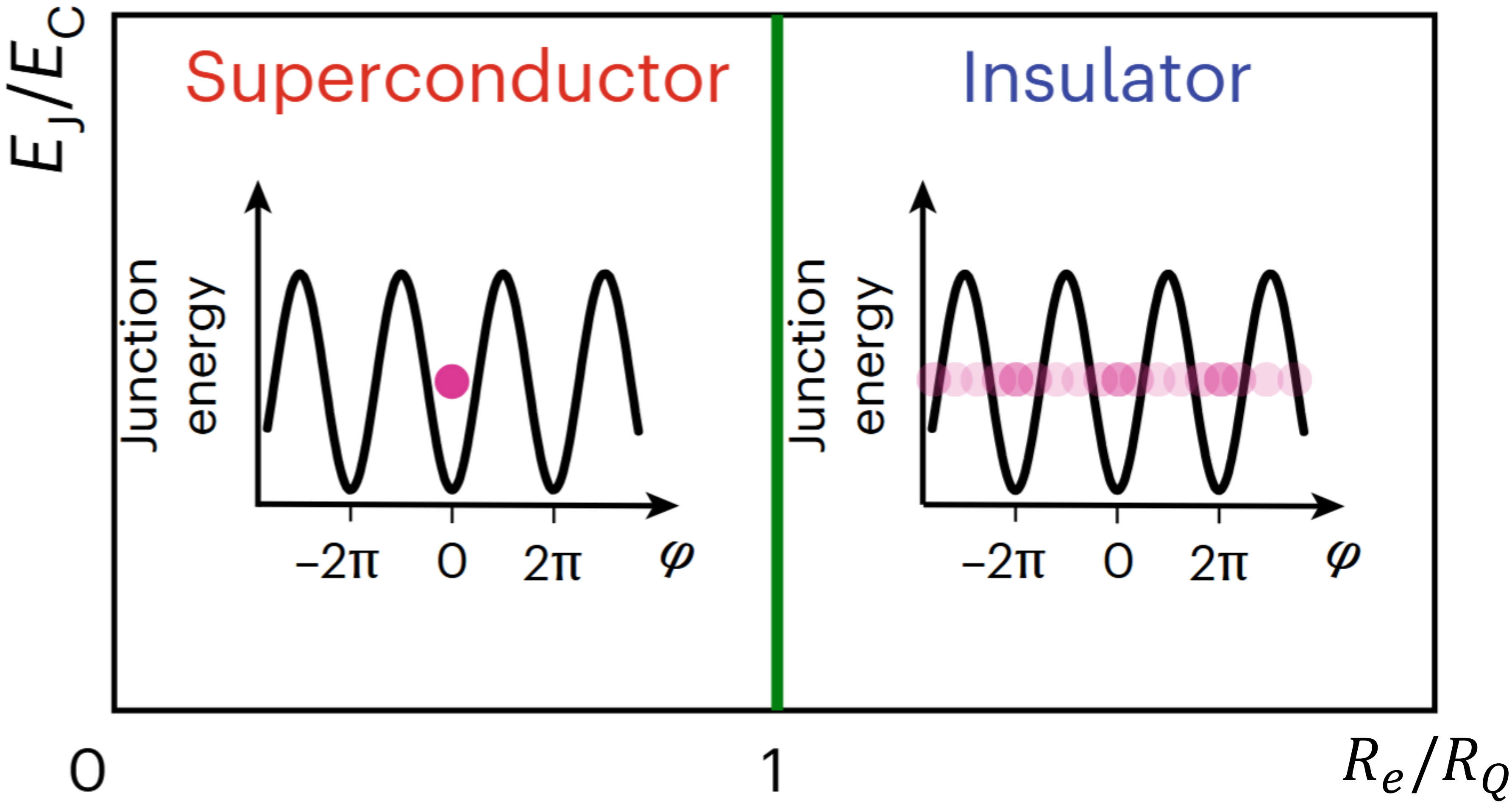


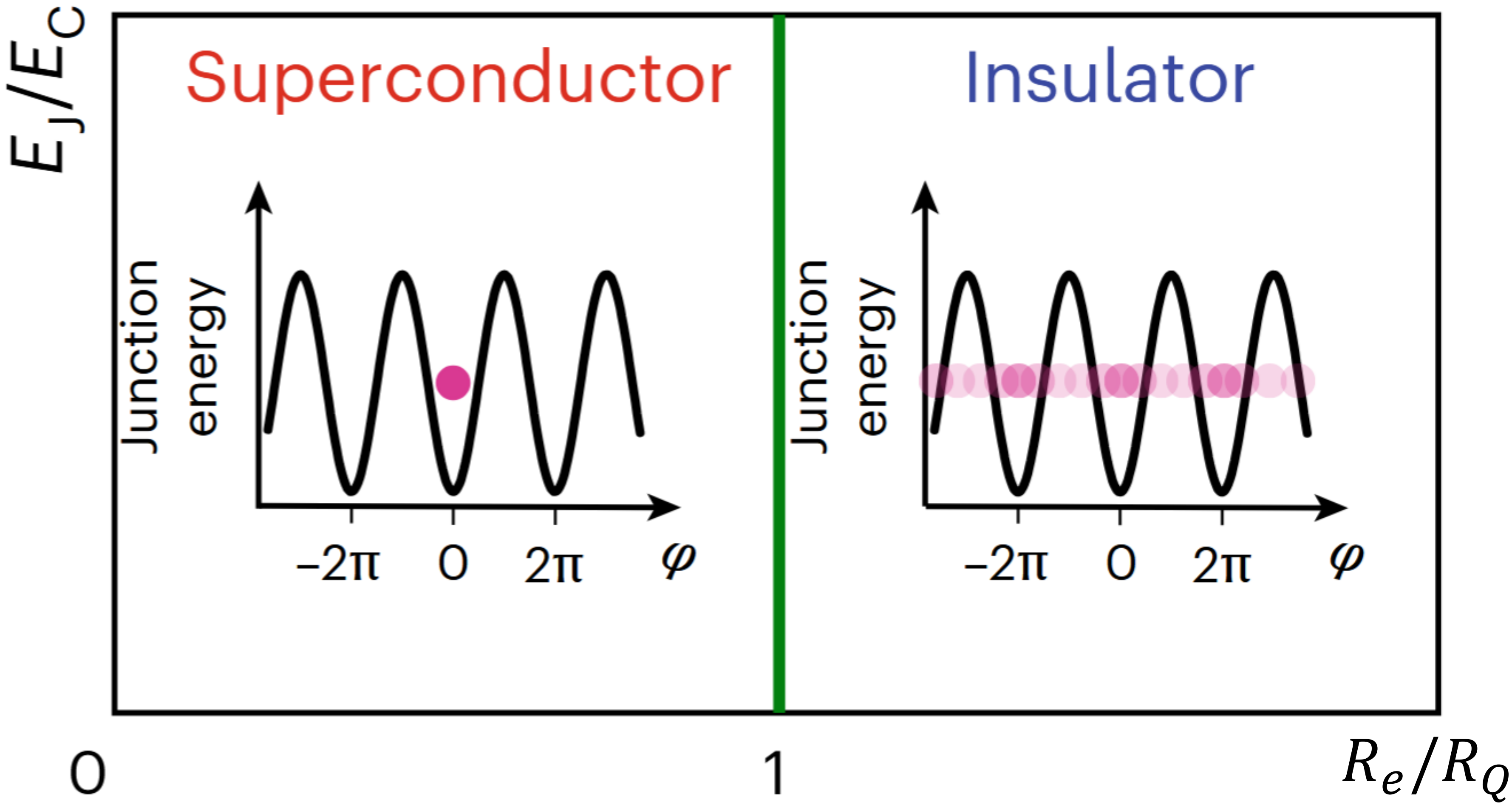
- Schmid and Bulgadaev (SB) worked on the quantum Brownian particle in a periodic potential (a problem that can be mapped on the RSJJ)
- Consequently, the RSJJ is equivalent problem to boundary sine-Gordon model in QFT

Dissipation driven phase transition



High $\boldsymbol{R_e}$ induces voltage noise which couples to the superconducting phase

Dissipation driven phase transition



$[\varphi, Q] = 2ei \neq 0$

Anderson, 1964

The more phase is delocalized, the more charge is localized -> Insulator

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Why the confusion?

Does the transition exist experimentally?		
YES	NO	MAYBE?
Yagi et al. (1997)	Murani et al. (2020)	Subero et al. (2023)
Kuzmin et al. (2024)	Murani et al. (2021)	

-"Would the predicted insulating phase exist, the junctions would be in the quantum critical regime where one expects the junction admittance to follow a power law of the temperature [28]. <u>This is clearly not the case in our experiments</u>."

-"In the second step, we explain the exact nature of the predicted transition and provide arguments according to which <u>JJs are actually not expected to become insulating in any Ohmic environment</u>."

This caused theoretical debates

- What is the role of ***T***?
- E_J / E_C influence?
- "True Resistive" environment? Frequency effects?

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[8] T. Morel and C. Mora, Double-periodic josephson junctions in a quantum dissipative environment, Phys. Rev. B **104**, 245417 (2021).
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[10] K. Masuki, H. Sudo, M. Oshikawa, and Y. Ashida, Absence versus presence of dissipative quantum phase transition in Josephson junctions, Phys. Rev. Lett. **129**, 087001 (2022).
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[15] T. Yokota, K. Masuki, and Y. Ashida, Functional-renormalization-group approach to circuit quantum electrodynamics, Phys. Rev. A **107**, 043709 (2023).
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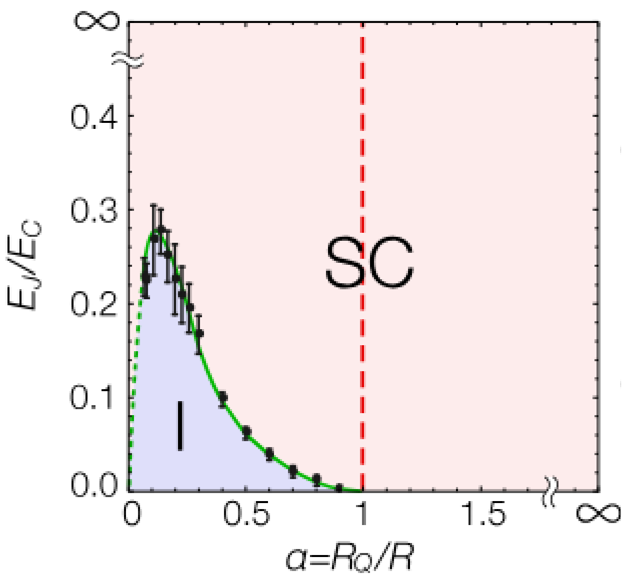
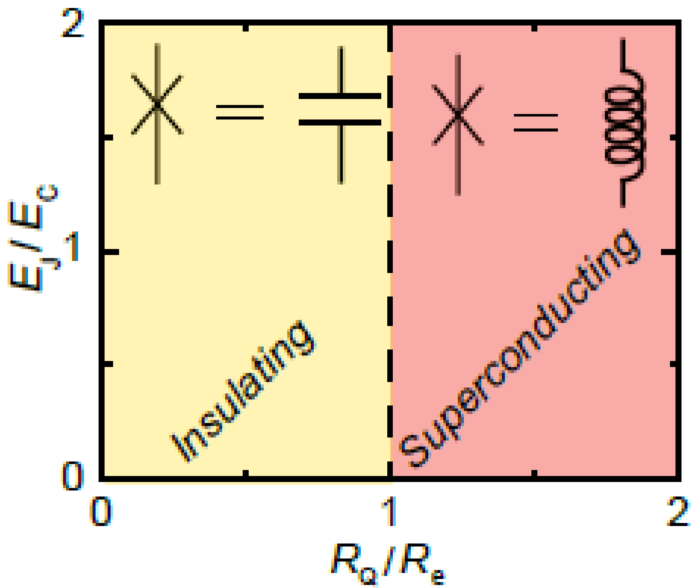
[21] O. Kashuba and R.-P. Riwar, Limitations of caldeira-leggett model for description of phase transitions in superconducting circuits, Phys. Rev. B **110**, 184505 (2024).
[22] B. Remez, V. D. Kurilovich, M. Rieger, and L. I. Glazman, Bloch oscillations in a transmon embedded in a resonant electromagnetic environment, Phys. Rev. B **110**, 054508 (2024).
[23] V. D. Kurilovich, B. Remez, and L. I. Glazman, Quantum theory of bloch oscillations in a resistively shunted transmon, Nature Communications **16**, 1384 (2025).





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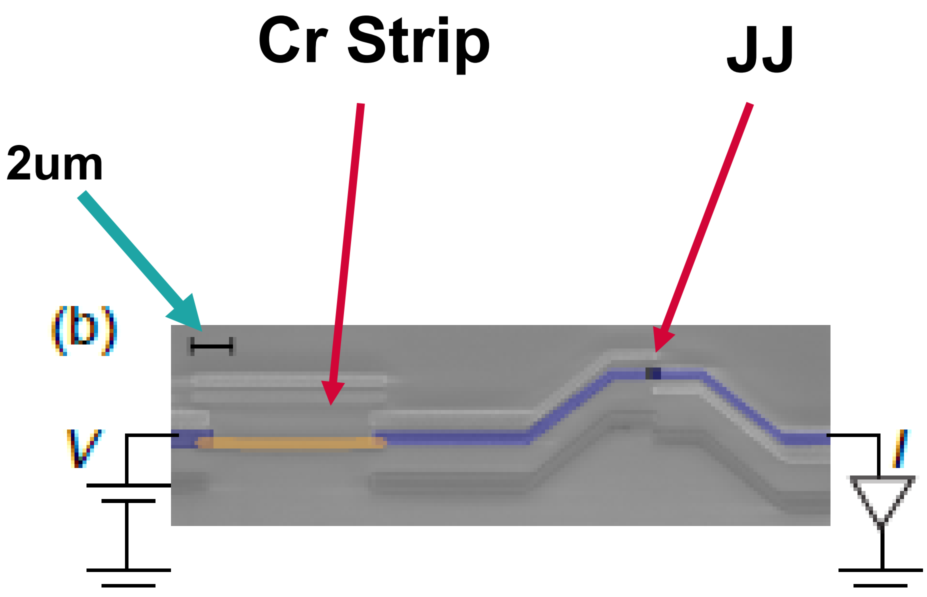
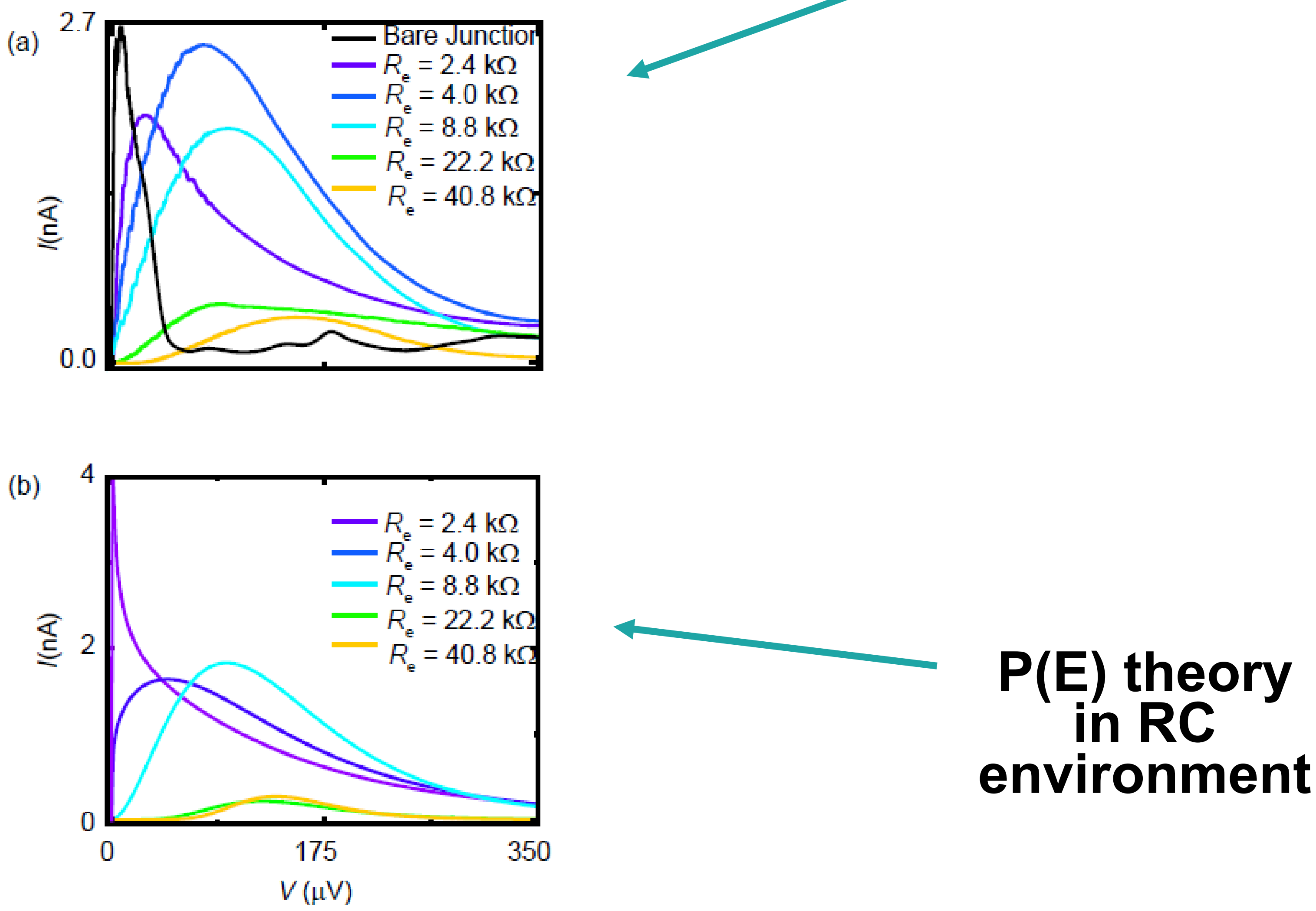
Experiment Devices



Determined by measuring isolated JJ device

device	R_J (kΩ)	E_J (K)	R_e (kΩ)	L (μm)
1			2.43	1
2	22.6	0.330	4.00	2
3			8.80	4
4	73.3	0.102	22.2	10
5			40.8	20

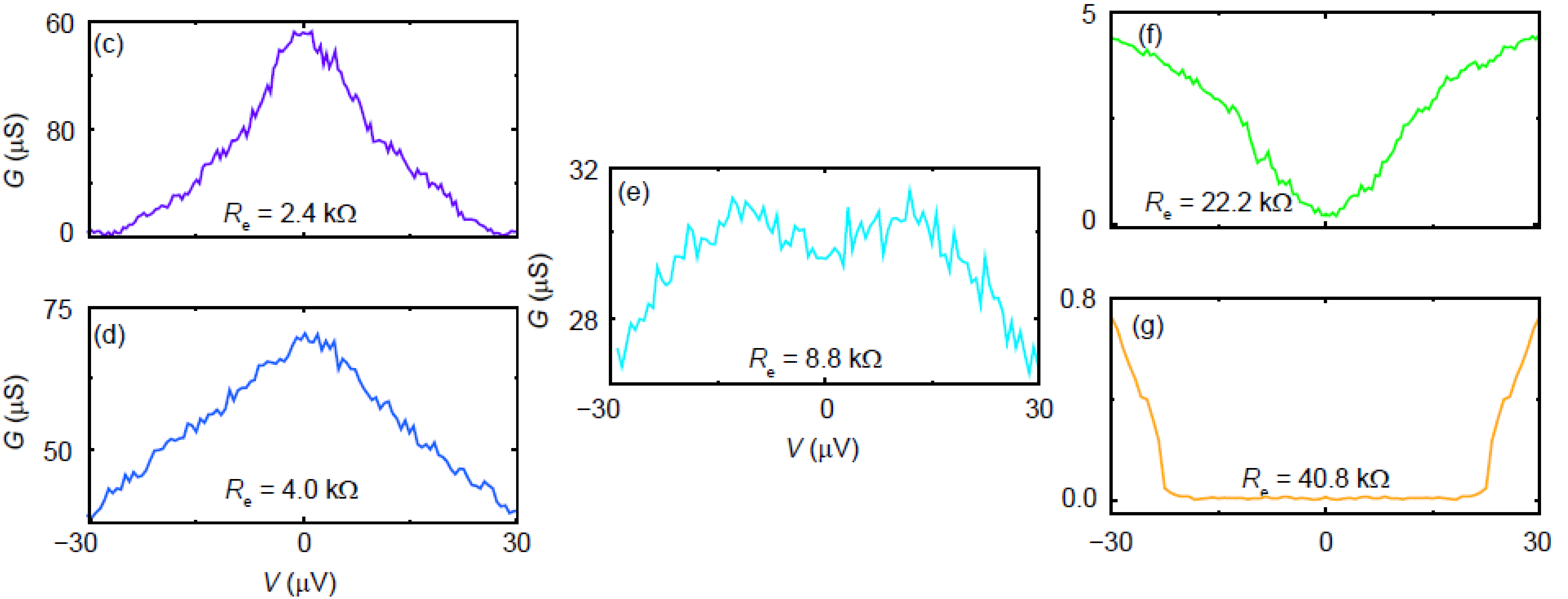
IV check



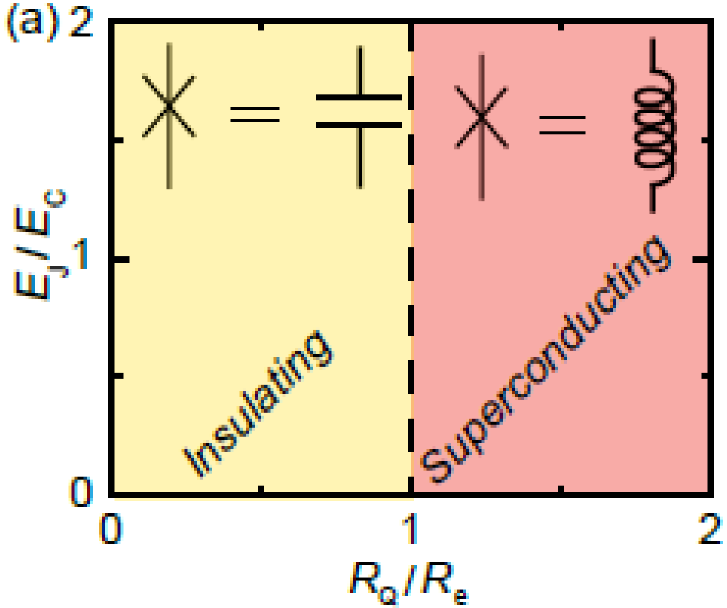
(a)
2.7
0.0
I(nA)
Bare Junction
R_e = 2.4 kΩ
R_e = 4.0 kΩ
R_e = 8.8 kΩ
R_e = 22.2 kΩ
R_e = 40.8 kΩ
(b)
4
2
0
I(nA)
R_e = 2.4 kΩ
R_e = 4.0 kΩ
R_e = 8.8 kΩ
R_e = 22.2 kΩ
R_e = 40.8 kΩ
0
175
350
V (μV)
Experiment
P(E) theory
in RC
environment

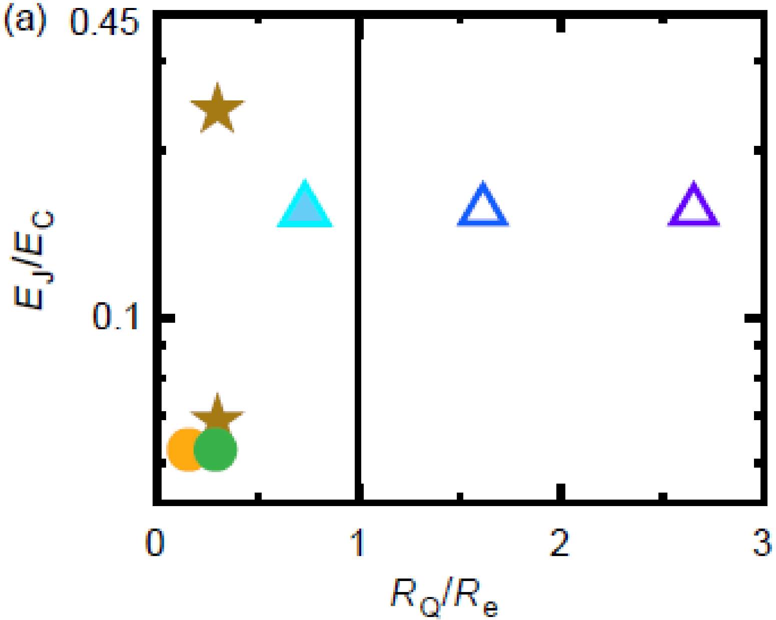
Low Frequency Bias Sweeps

$R_e < R_Q$ $\quad$ $R_e \approx R_Q$ $\quad$ $R_e > R_Q$



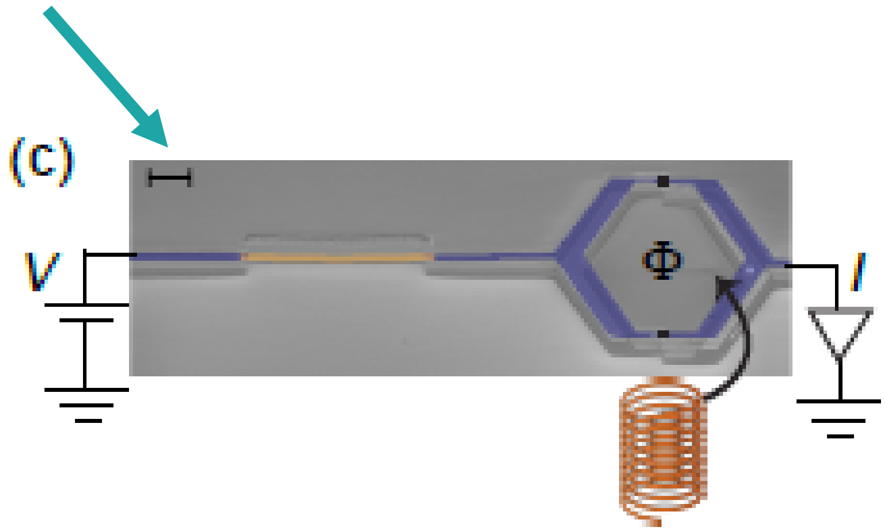
So far agrees with the prediction for R
What about energies?





Experiment Devices

2um



Capacitance was obtained by fitting IV with P(E) model

Device	JJ area (nm^2)	$R_J (k\Omega)$	C^{Fit} (fF)	E_J (K)	E_C (K)
(a)	180×50	20.49	0.80	0.375	1.20
(b)	150×50	51.80	0.42	0.145	2.21
(c)	100×50	62.87	0.40	0.119	2.30

$R_e = 19.2\ k\Omega$

$\Phi/\Phi_0 = 0$

↓

$\Phi/\Phi_0 = 0.5$

Device	JJ area (nm^2)	$R_J (k\Omega)$	C^{Fit} (fF)	E_J (K)	E_C (K)
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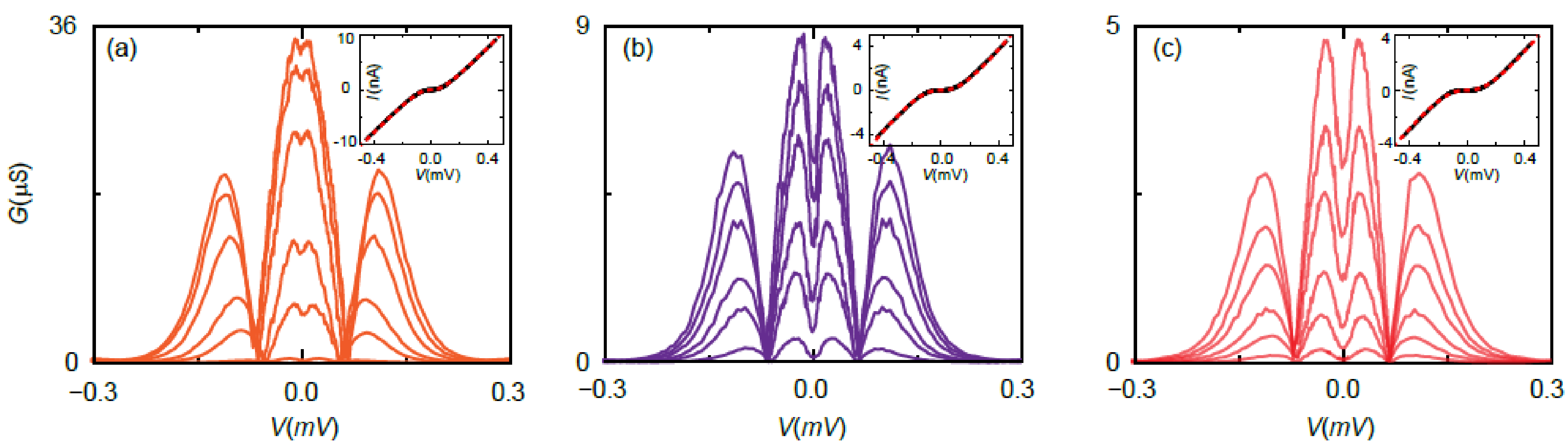
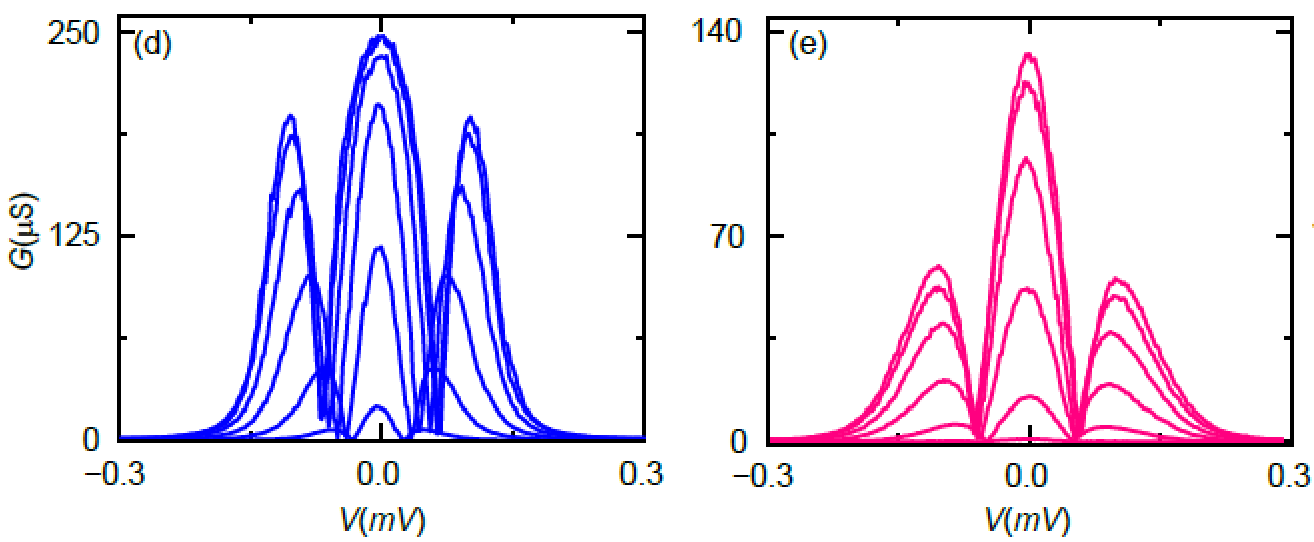


JJ area (nm^2)	R_e(kΩ)	R_J(kΩ)	$C^{\square}$(fF)	E_J (K)	E_C (K)
60 × 60	3.3	12.4	0.18	0.60	5.16
60 × 60	4.5	9.6	0.18	0.78	5.16

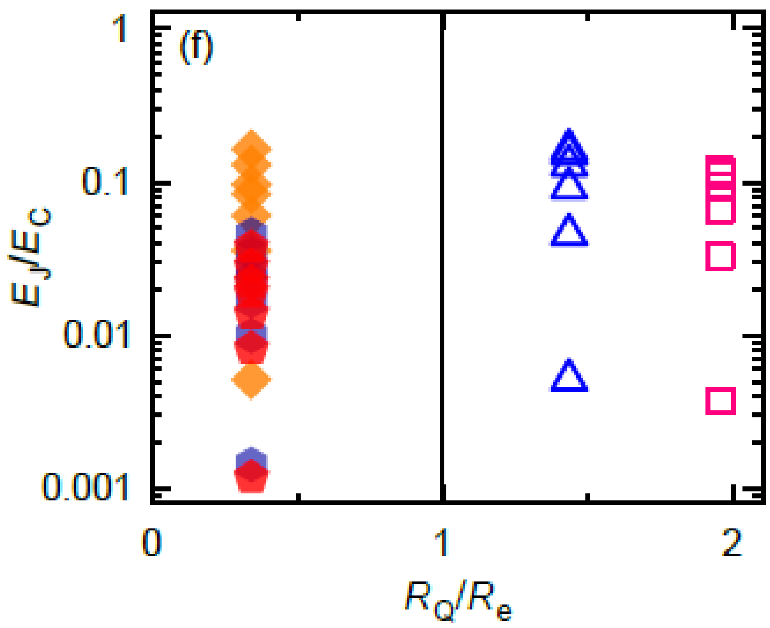
$\Phi/\Phi_0 = 0$

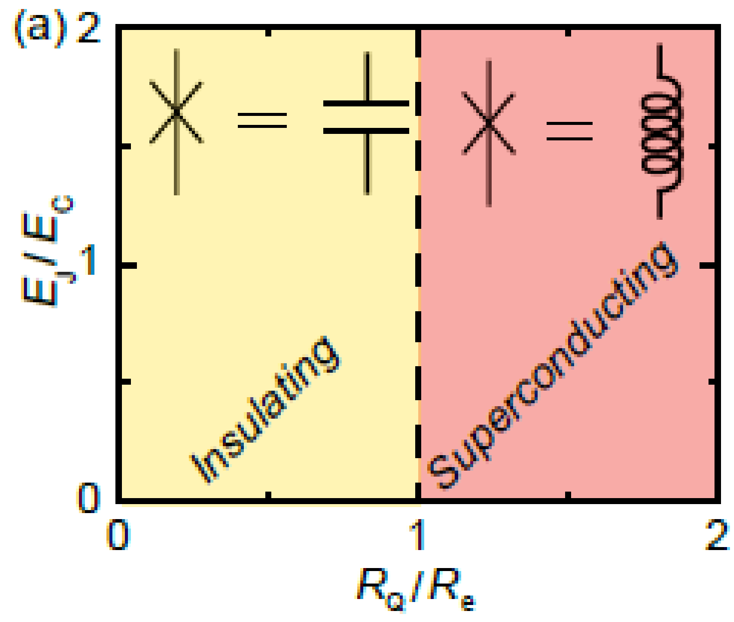
↓

$\Phi/\Phi_0 = 0.5$

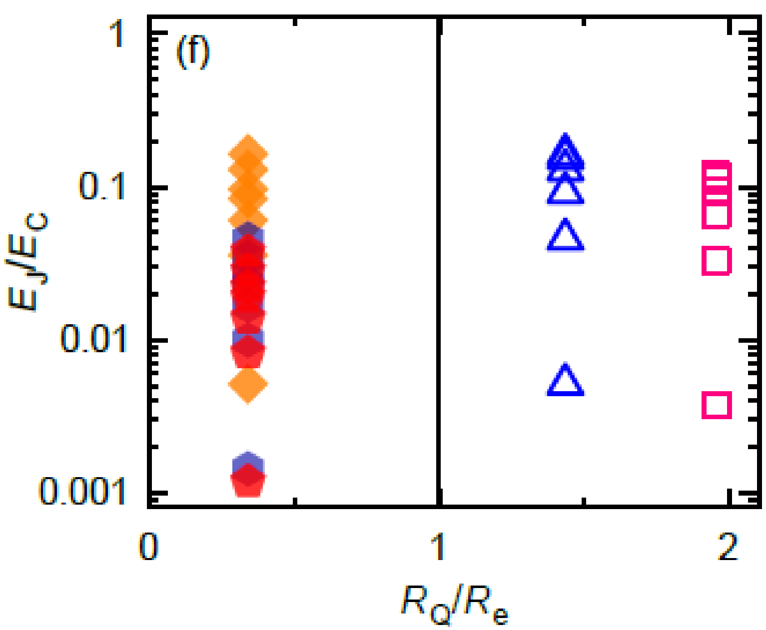


Claims to be independent of Ej/Ec ratio





Close call



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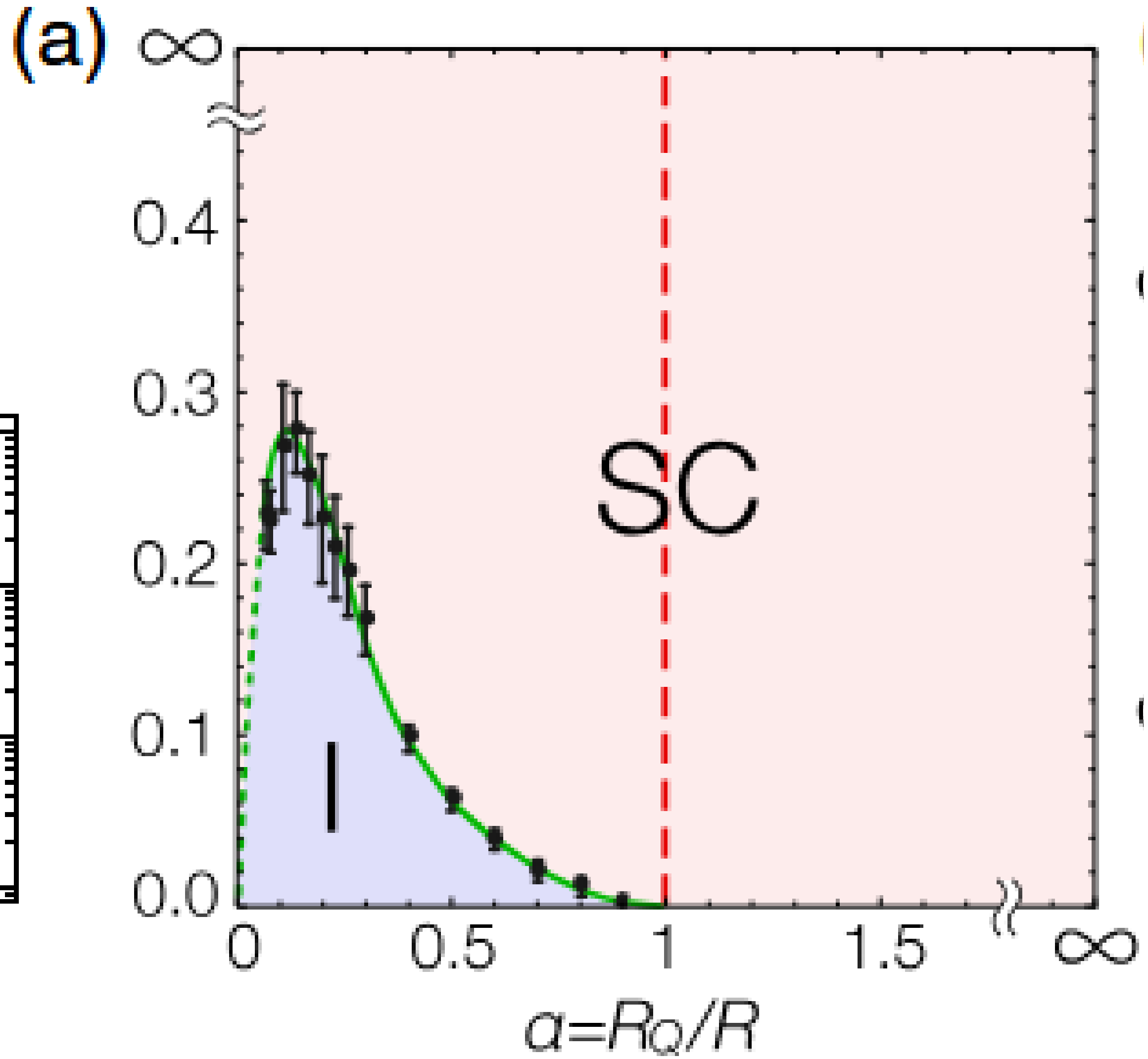

0.34

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Conclusions

- Even after so much theoretical and experimental effort, the exact dynamics of this phase transition are still unclear
- Original predictions are mostly proven
- Not many direct applications but many fields are benefit from understanding the mechanism

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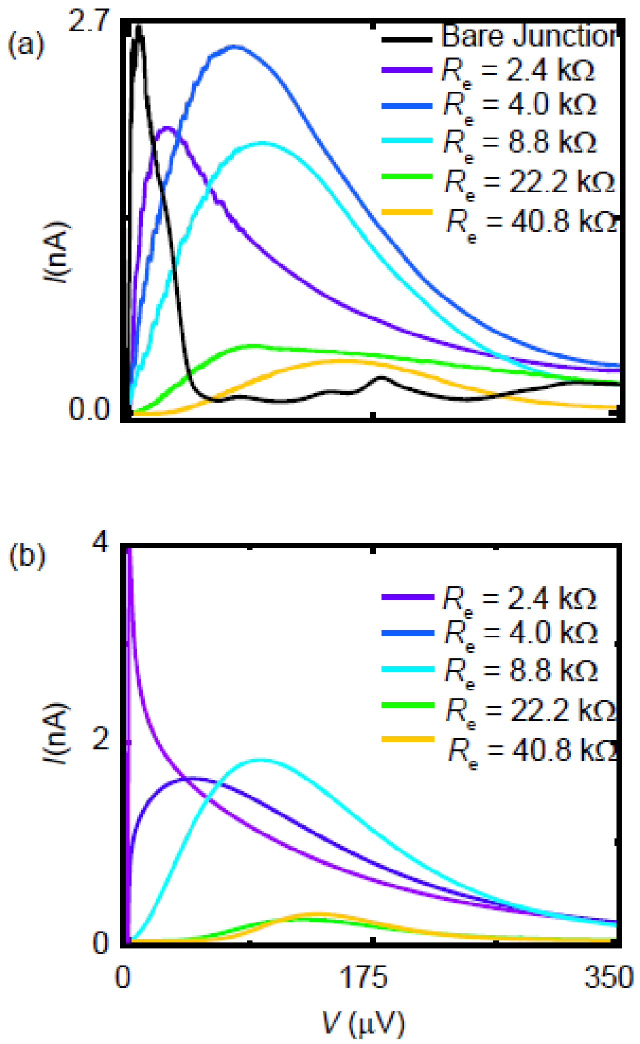
Thank you
for your attention.

What about temperature?



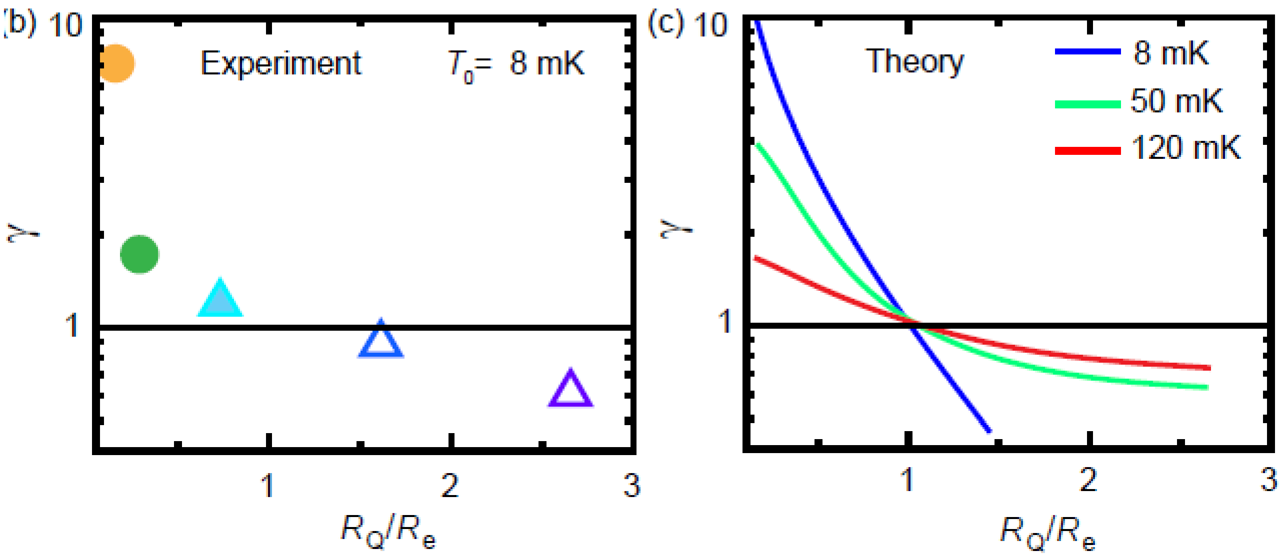
$$I \propto V^{\gamma}$$

$$\gamma = \frac{2R_e}{R_Q} - 1$$

At T=0, transition occurs when gamma =1

What about temperature?

$I \propto V^{\gamma}$



P(E) theory in RC environment