Coherent Quantum Phase Slips

O. V. Astafiev, et al.
Nature **484**, 355–358 (2012)

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16 November, 2012
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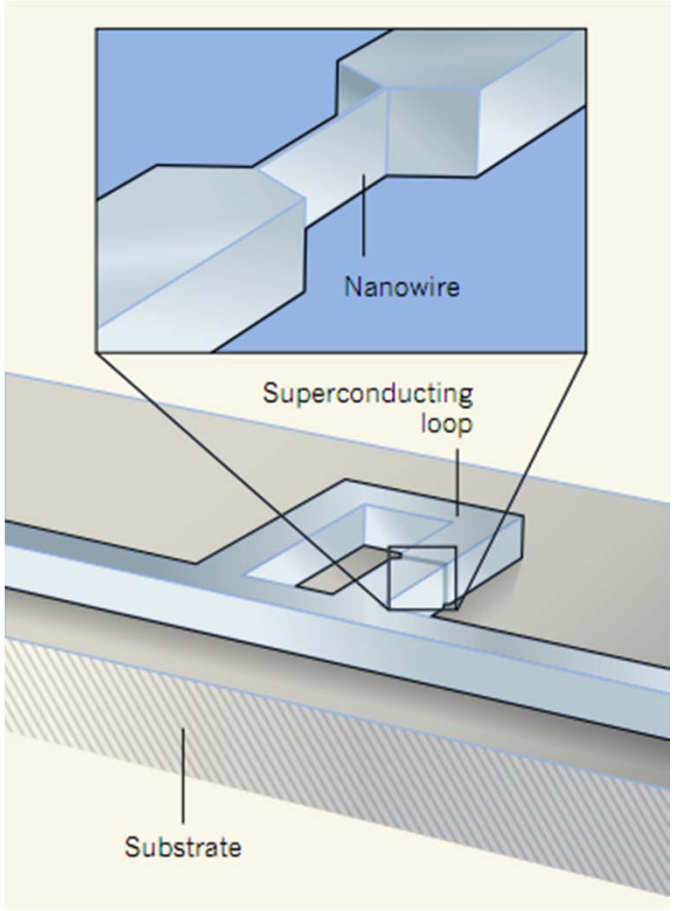
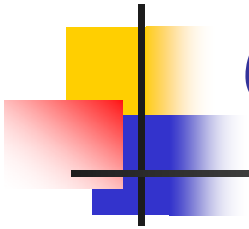


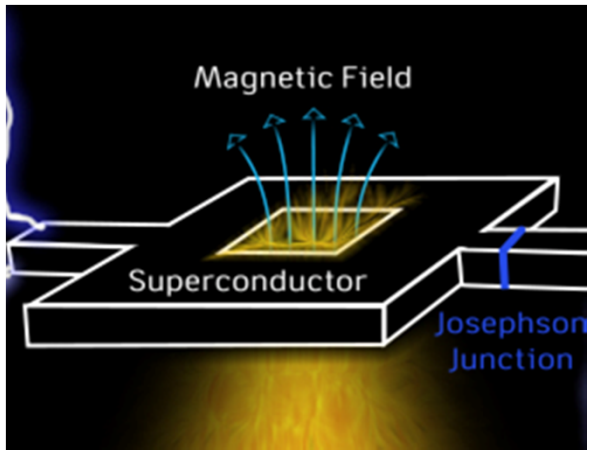


Outline

- Background
- Experimental methods
- Results
- Critical Analysis
- Summary and Conclusions

Quantum Phase Slips (QPS) in Superconductors

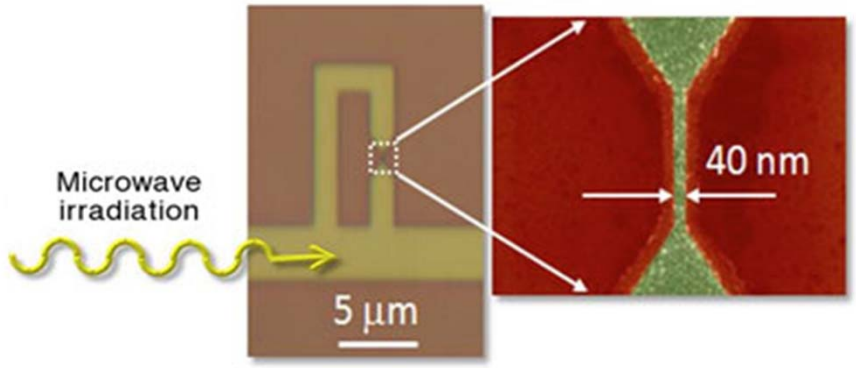
- Flux is quantized, the quantum is $\phi_0 = \frac{h}{2e}$
- Order parameter is a complex variable, its phase will fluctuate $\psi(x) = e^{-i\phi(x)}$
  - Current will change → flux will change
- QPS at different places interfere
  - Forms superposition of states(coherence)



Superconducting Quantum Interference Device(**SQUID**)
http://www.learner.org/courses/physics/

Sample : thin superconducting loop and narrow wire

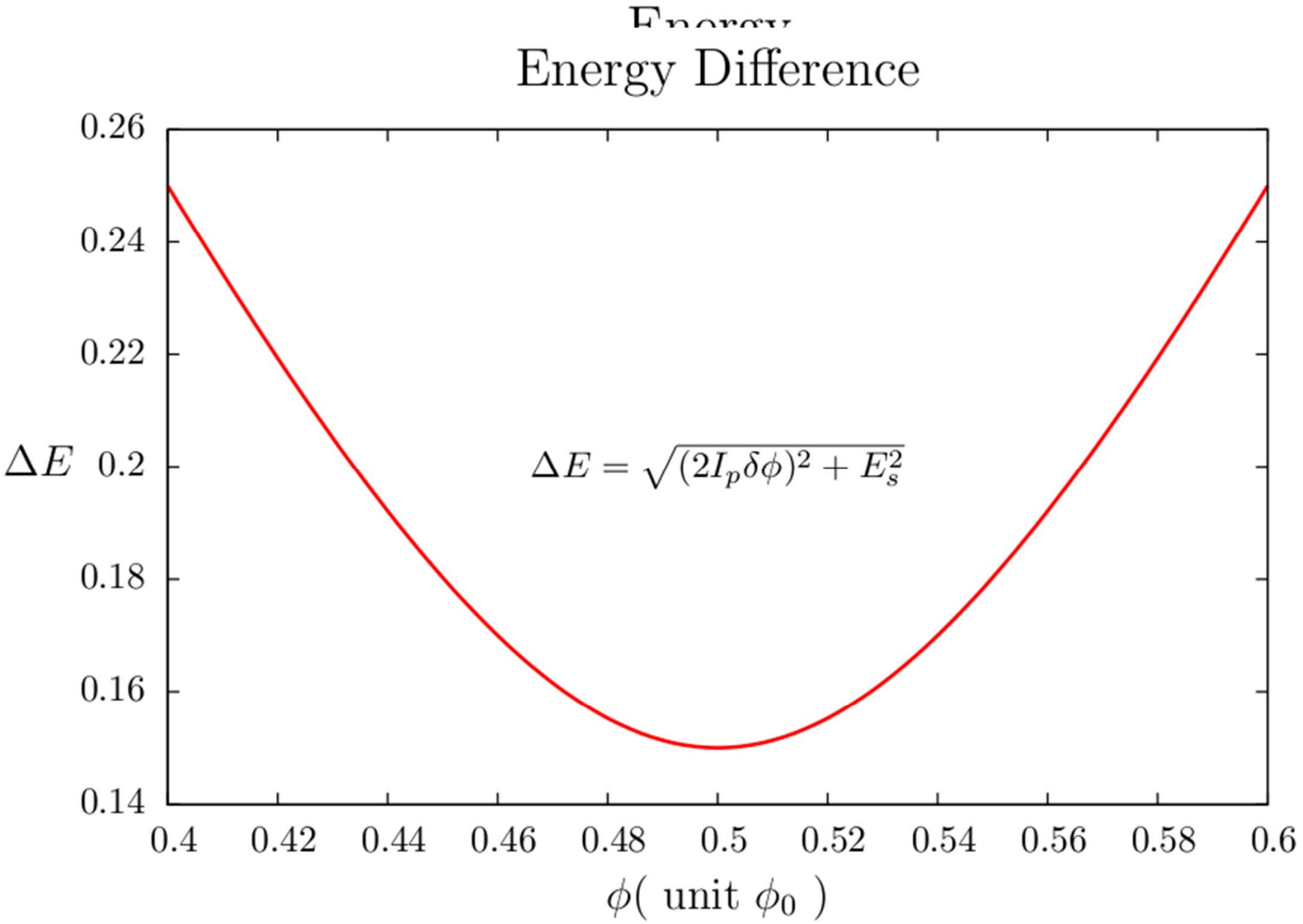
- InOx loop with a narrow wire segment



O. V. Astafiev at el (2012)

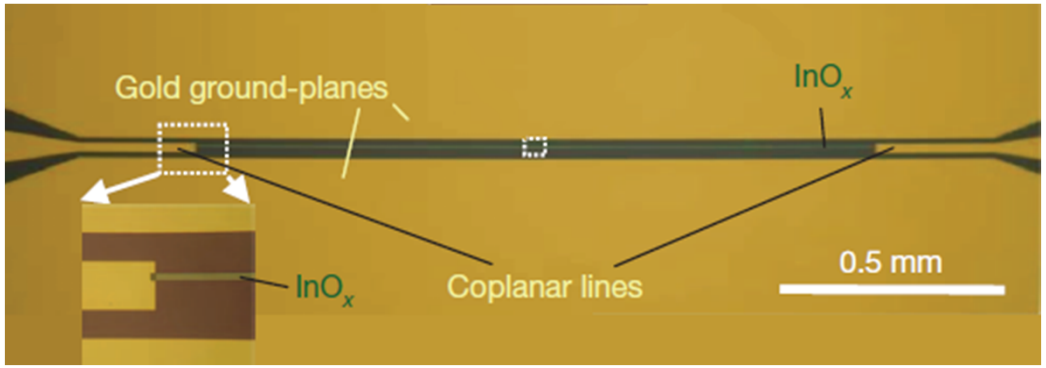
- Energy has a parabolic dependence on external flux

$$|N\rangle, \quad E_N = \frac{(\phi_{ext} - N\phi_0)^2}{L_k}, \quad \phi_{ext} = B_{ext}S$$

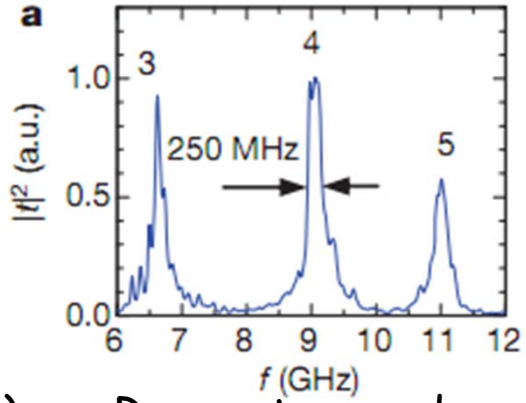

Energy Difference
0.26
0.24
0.22
0.2
0.18
0.16
0.14
ΔE
$\Delta E = \sqrt{(2I_p\delta\phi)^2 + E_s^2}$
0.4
0.42
0.44
0.46
0.48
0.5
0.52
0.54
0.56
0.58
0.6
ϕ(unit ϕ_0)

Microwaves used to detect phase slip signal

- Step-impedance coplanar resonator

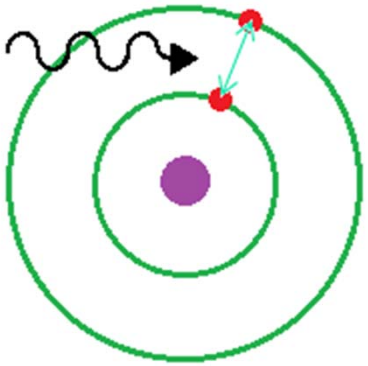


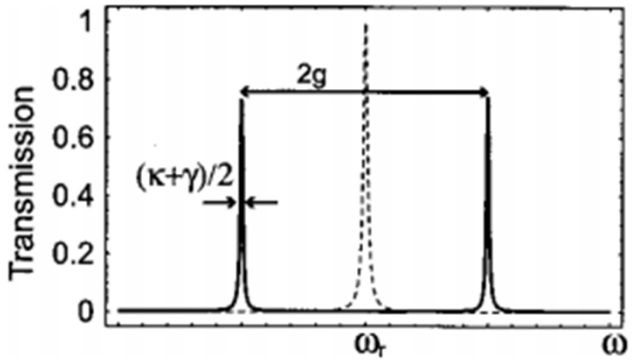
Step-impedance resonator O. V. Astafiev at el (2012)



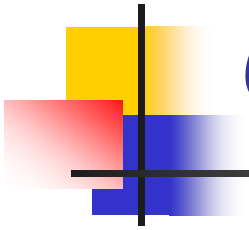
Resonator modes O. V. Astafiev at el (2012)

- Artificial atom





Phys.Rev.A 69, 062320 (2004)



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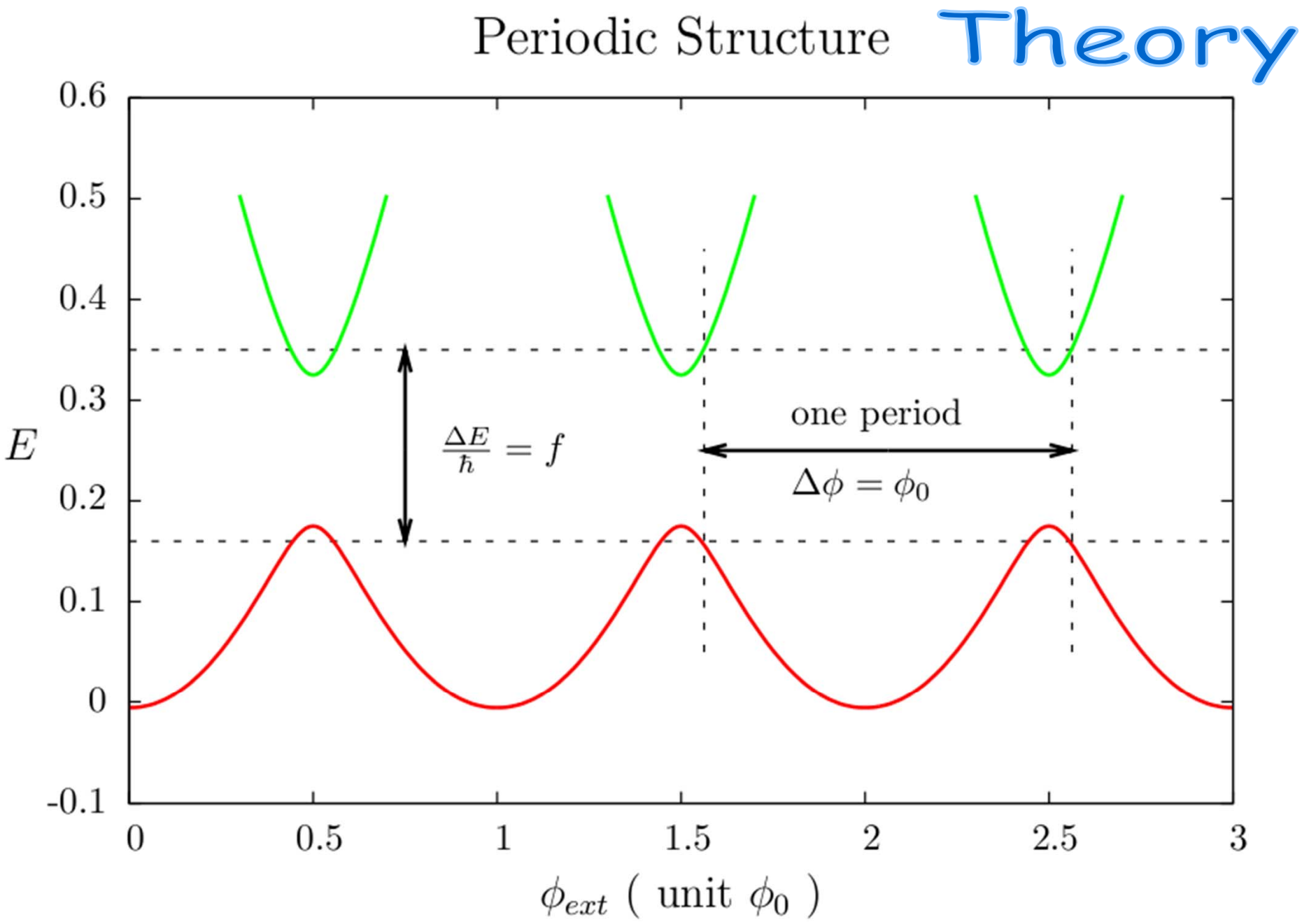
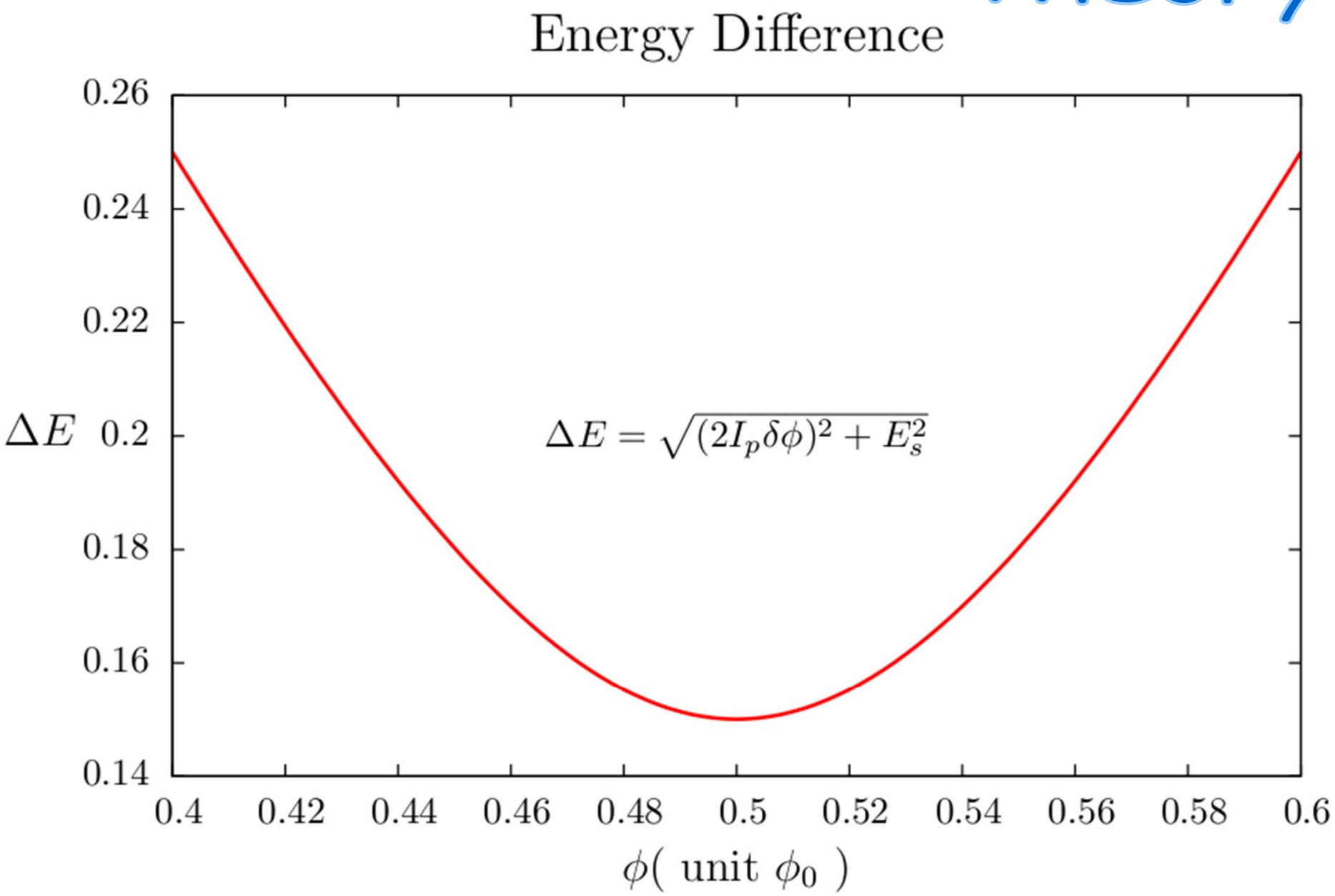

Periodic Structure
Theory
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
E
$\frac{\Delta E}{\hbar} = f$
one period
$\Delta\phi = \phi_0$
0
0.5
1
1.5
2
2.5
3
ϕ_{ext} (unit ϕ_0)

Theory


Energy Difference
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ΔE
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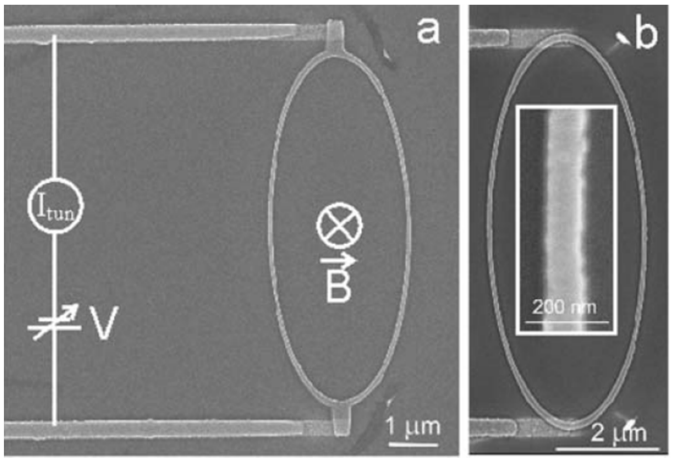
0.5
0.52
0.54
0.56
0.58
0.6
ϕ(unit ϕ_0)

Comparison with Previous Work

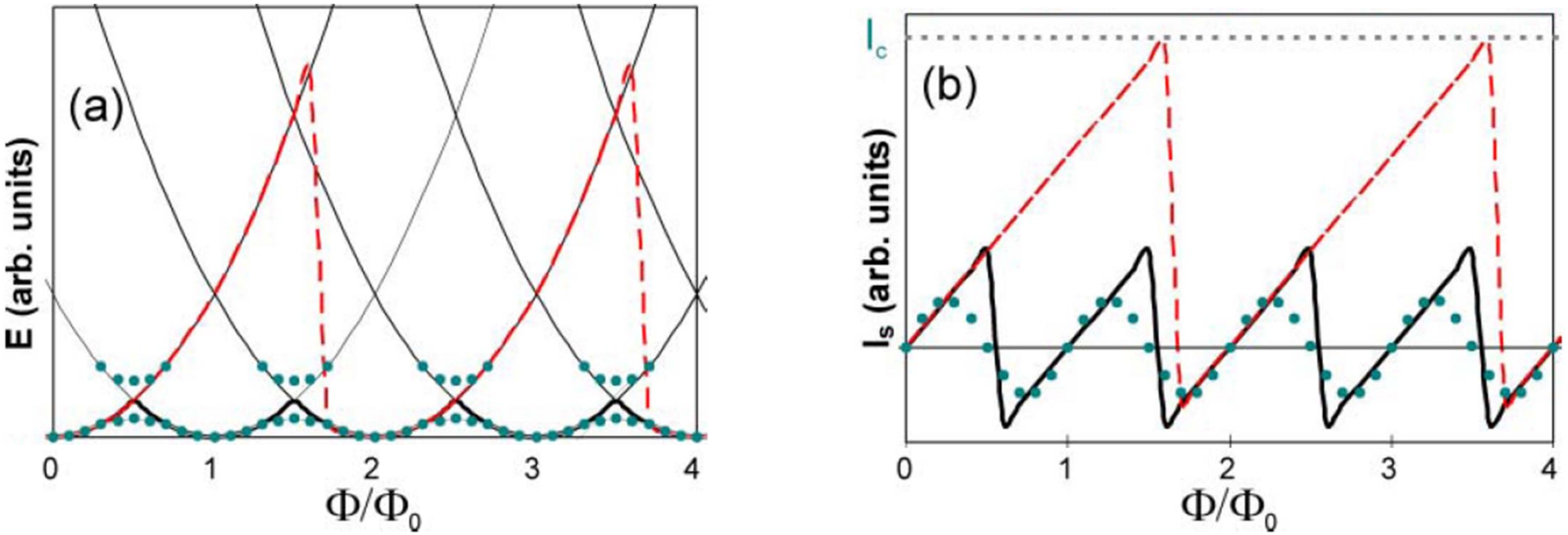
- Aryutunov, K. Y., *Scientific Reports* **2**, 293 (2012).
- Studied persistent currents in superconducting nanorings



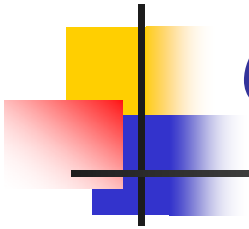
Scanning electron micrograph of nanoring (Aryutunov 2012)

- Key result: quenching of persistent currents is caused by quantum phase slips

Similar Energy Structure in Nanorings

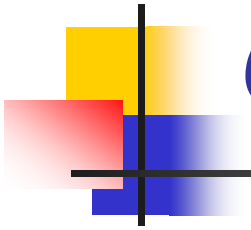


Theoretical energy spectrum (a) & persistent currents (b) of the nanoring as functions of external flux (Aryutunov 2012)



Critique of Aryutunov Paper

- Authors claim tunneling current properties are altered only by quantum phase slips.
- Rule out other alternatives, e.g., sample imperfections, thermal fluctuations, external noise.
- Not as convincing as coherent quantum phase slip (CQPS) paper.
- CQPS paper is more rigorous: performs energy measurements & fits to theoretical predictions.



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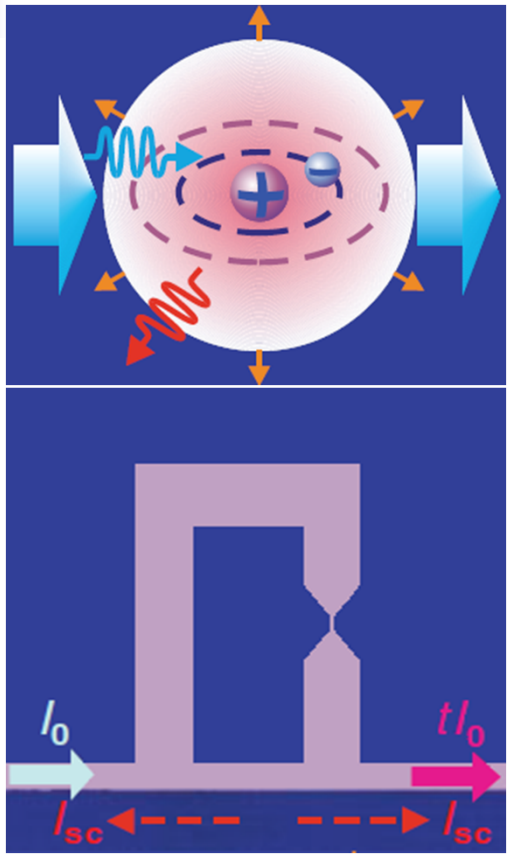
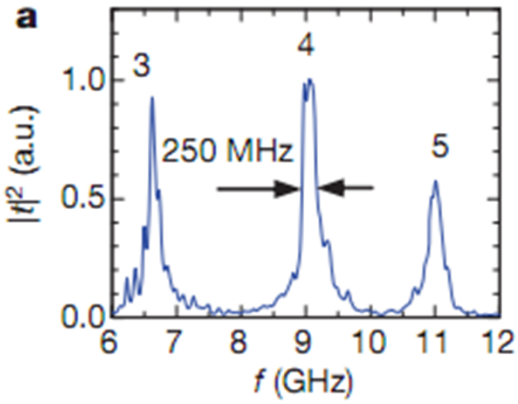
Good Choice of Material

- Purpose of the paper:
  - to observe coherent quantum phase slip
- Required property of the material:
  - high degree of disorder
  - have pre-formed cooper pairs
- Sizeable phase slip energy E_S:
  - close to superconductor-insulator transition
  - narrow wires
- Best choice of materials:
  - InO_x and TiN

Good Choice of Probing Technique



- A well-established technique
- Provide strong coupling between loop and resonator

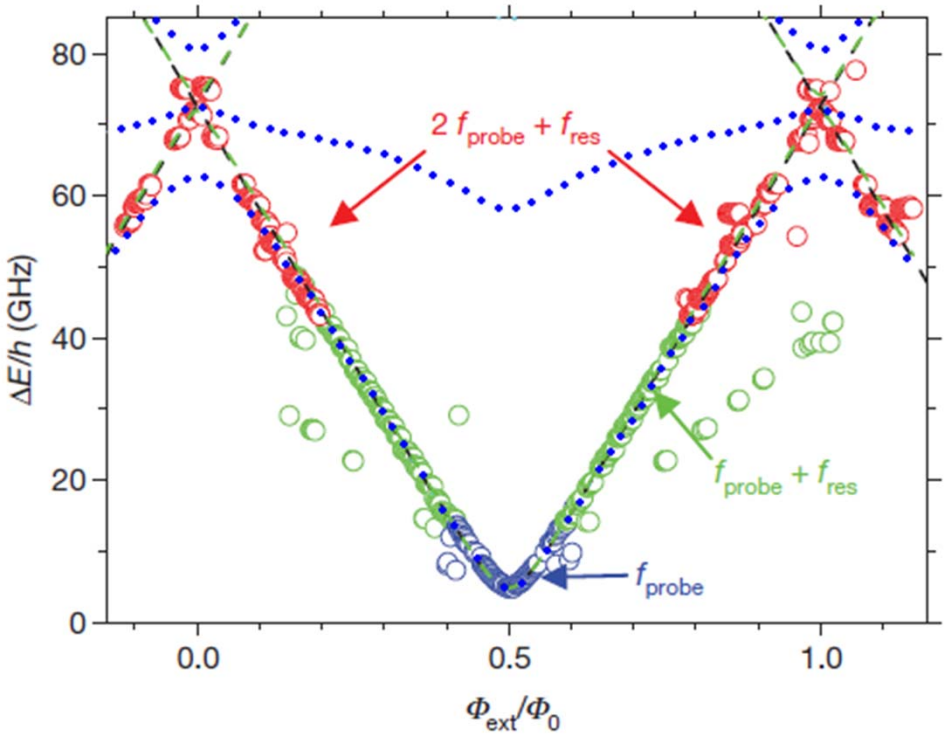


Sketch of a natural atom in open space and an artificial atom coupled to a 1D transmission line.

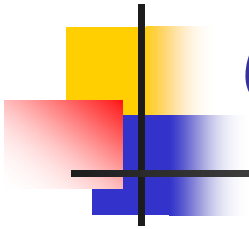
O. Astafiev, *et al. Science* **327**, 840-843 (2010)

Evidence for excluding Rogue Josephson Junction

- Three samples are measured
- Linear dependence of the energy difference



Spectroscopy of the system across a wide range of flux and frequency.
(Astafiev 2012)



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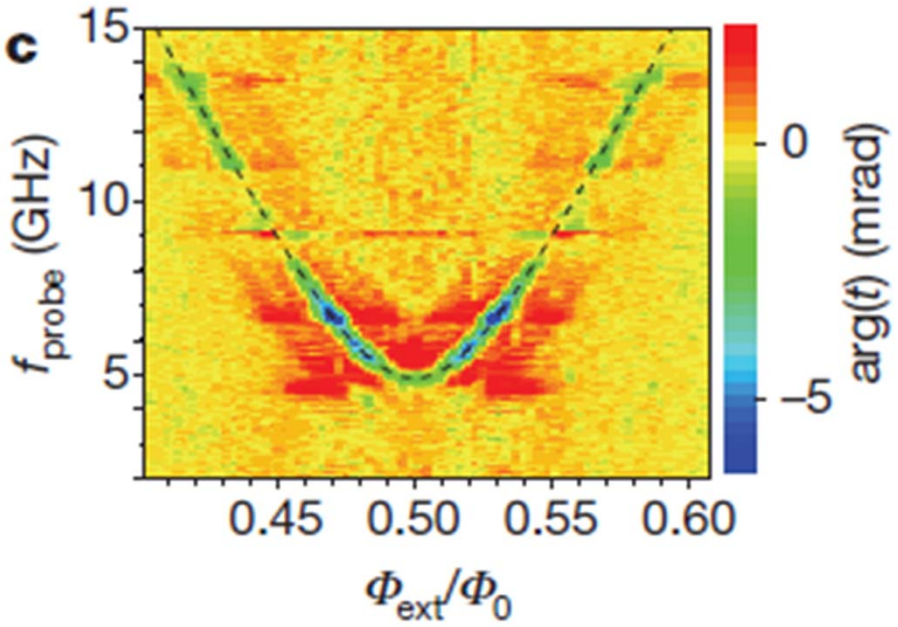
Summary

- Step-impedance coplanar resonator was used to detect coherent quantum phase slip.
- First experimental verification of coherent quantum phase slip.



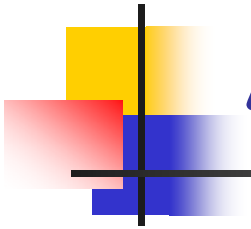
The two-level spectroscopy line obtained in two-tone measurements.

(Astafiev 2012)

Citation evaluation

- Since publication in April 2012, Cited by
  - 5 (Web of Knowledge)
  - 13 (Google Scholar)

- No directly relevant work



Acknowledgments

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- O. V. Astafiev *et al.*

Thank you for your attention!