Josephson-Leggett modes in a Dirac semimetal Cd3As2-based SQUID

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2021 Intern Symposium

Quantum computing

0

Classical bit

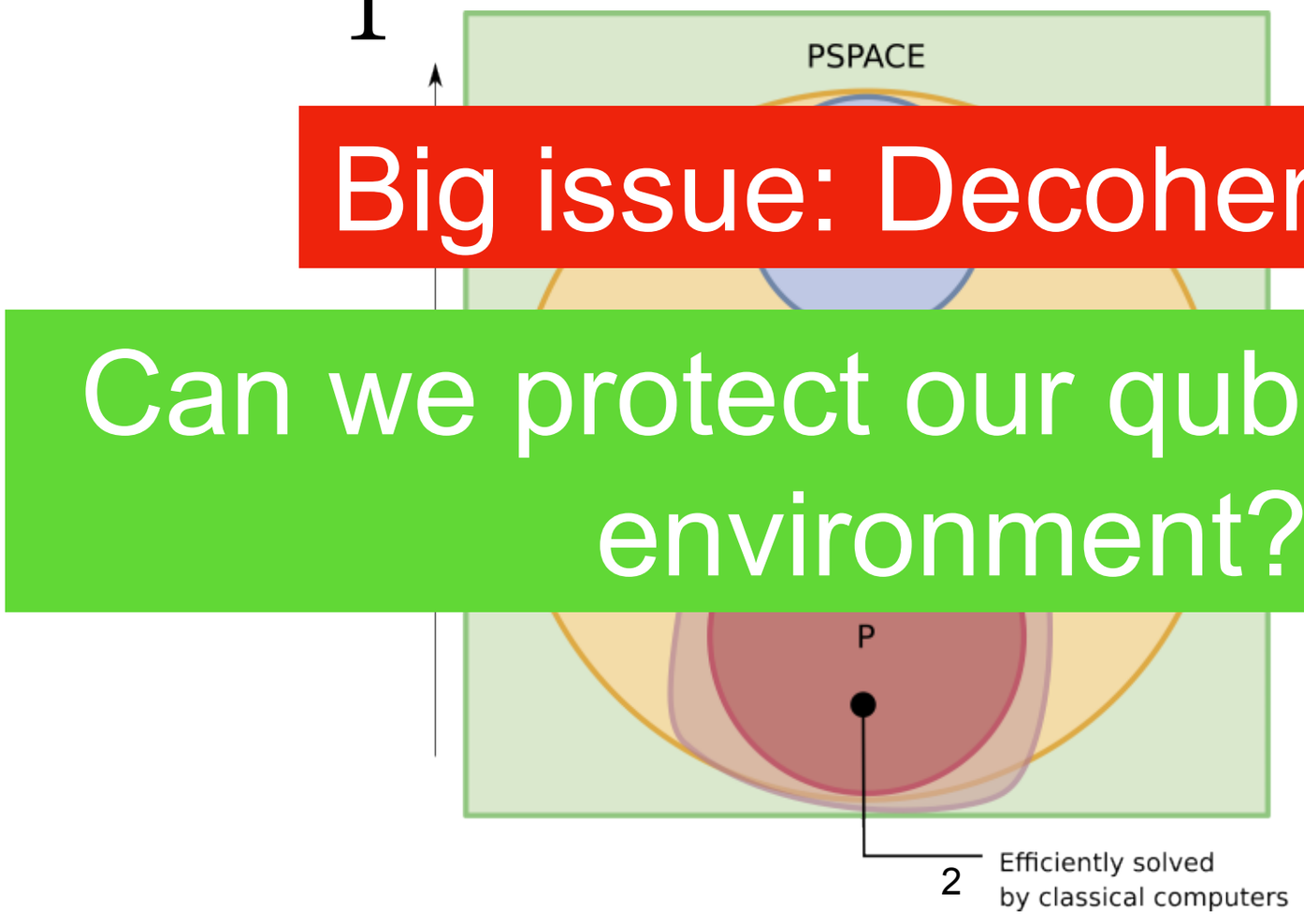
1

Qubit

$|0>$

$\alpha|0> + \beta|1>$

$|1>$



Big issue: Decoherence

Can we protect our qubit from the environment?

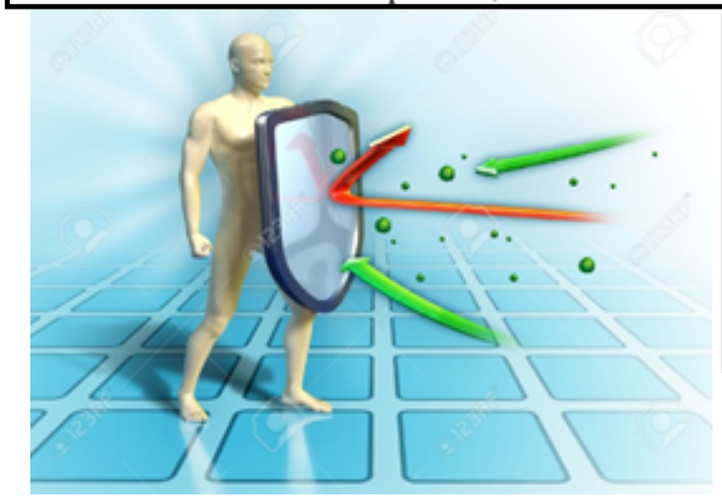
ring
break
public key cryptography
schemes!

Topological Protection

PHYSICAL REVIEW X **6,** 031016 (2016)

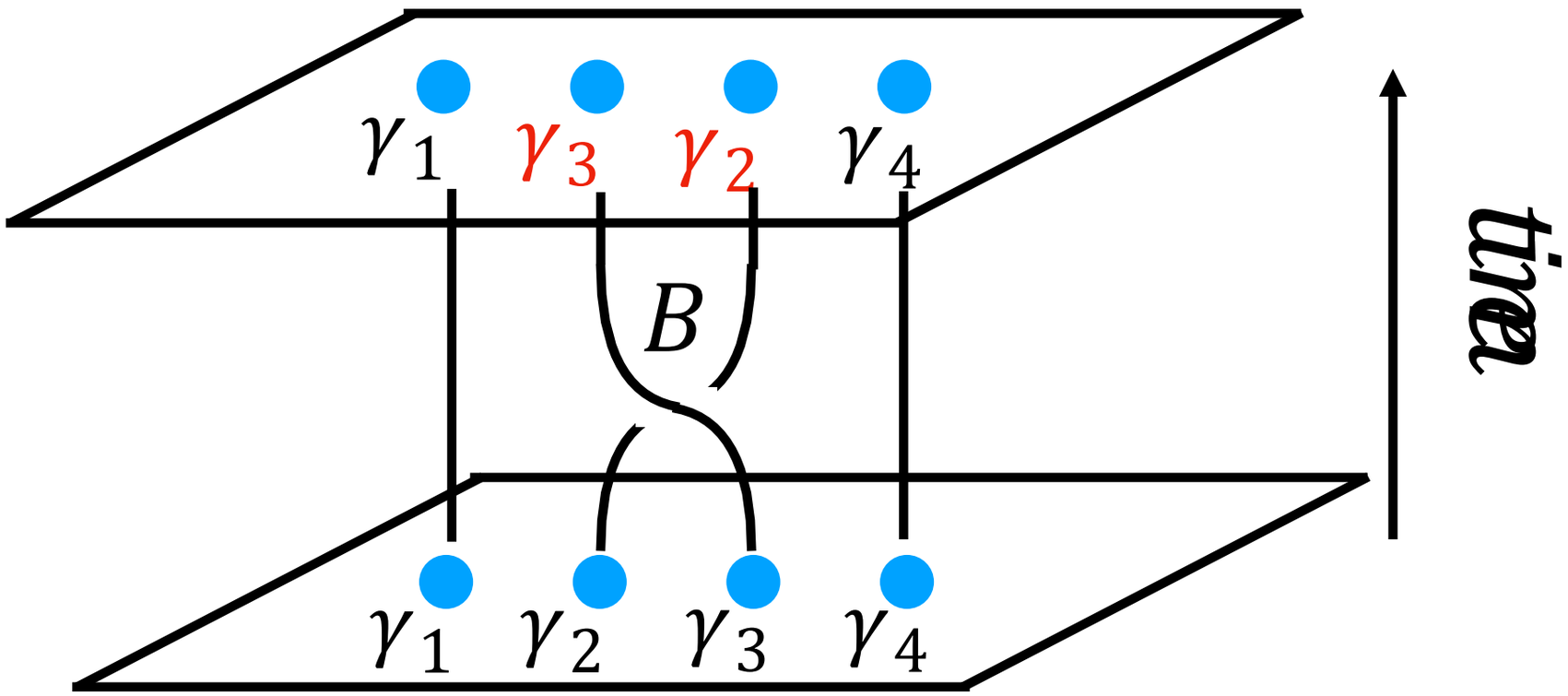
Milestones Toward Majorana-Based Quantum Computing

David Aasen,[1] Michael Hell,[2,3] Ryan V. Mishmash,[1,4] Andrew Higginbotham,[5,3] Jeroen Danon,[3,6] Martin Leijnse,[2,3] Thomas S. Jespersen,[3] Joshua A. Folk,[3,7,8] Charles M. Marcus,[3] Karsten Flensberg,[3] and Jason Alicea[1,4]



Non-Abelian anyons and topological quantum computation

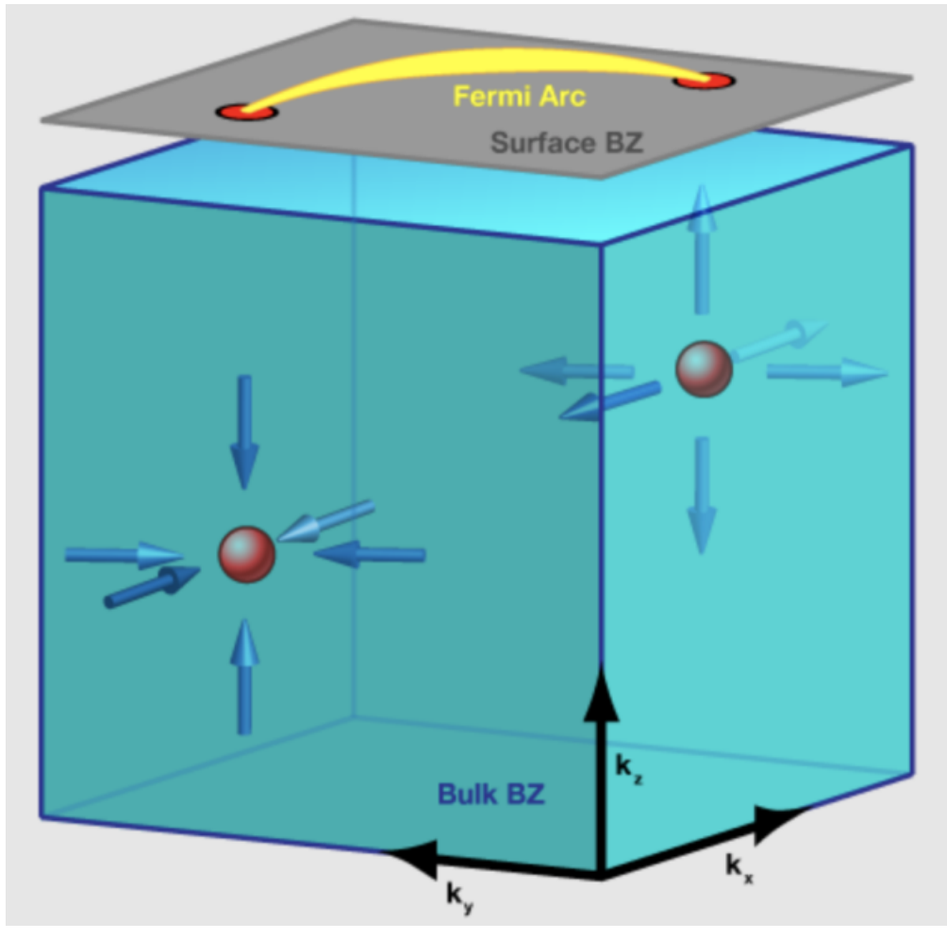
Chetan Nayak, Steven H. Simon, Ady Stern, Michael Freedman, and Sankar Das Sarma
Rev. Mod. Phys. **80**, 1083 – Published 12 September 2008

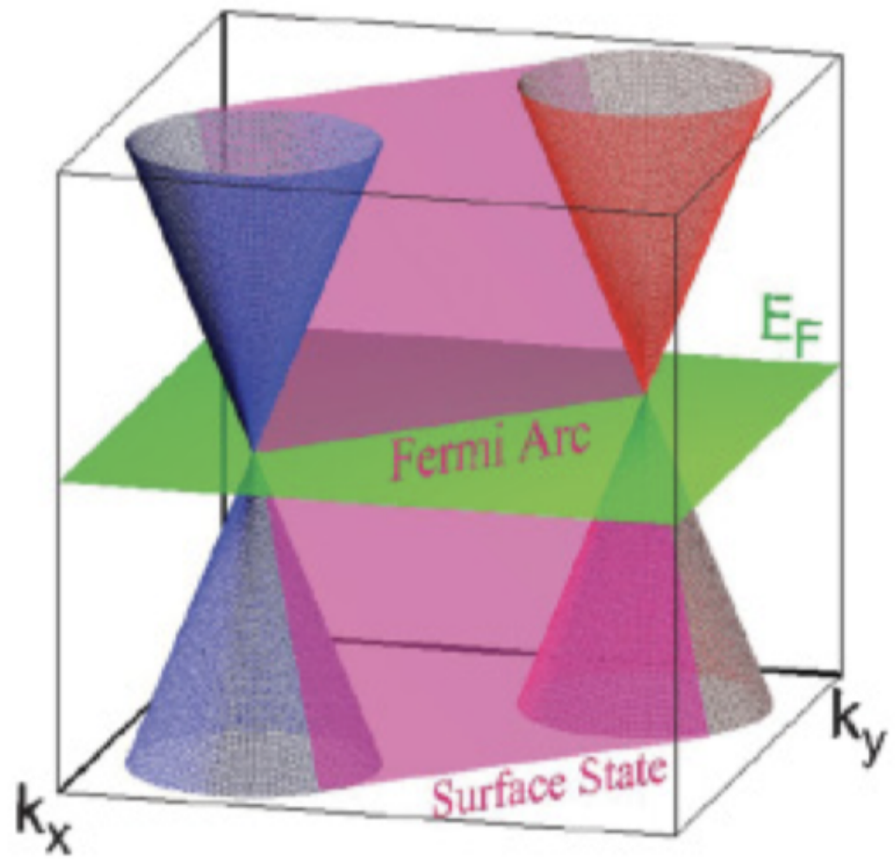


Use global operation of braiding topologically-protected states to perform quantum operations

$|Q_1, Q_2>$ → **Unitary braiding operations** → $|\tilde{Q}_1, \tilde{Q}_2>$

Dirac & Weyl Semimetals





PHYSICAL REVIEW B **95**, 174505 (2017)

Josephson current signatures of Majorana flat bands on the surface of time-reversal-invariant Weyl and Dirac semimetals

Anffany Chen,[1,2] D. I. Pikulin,[1,2,3] and M. Franz[1,2]

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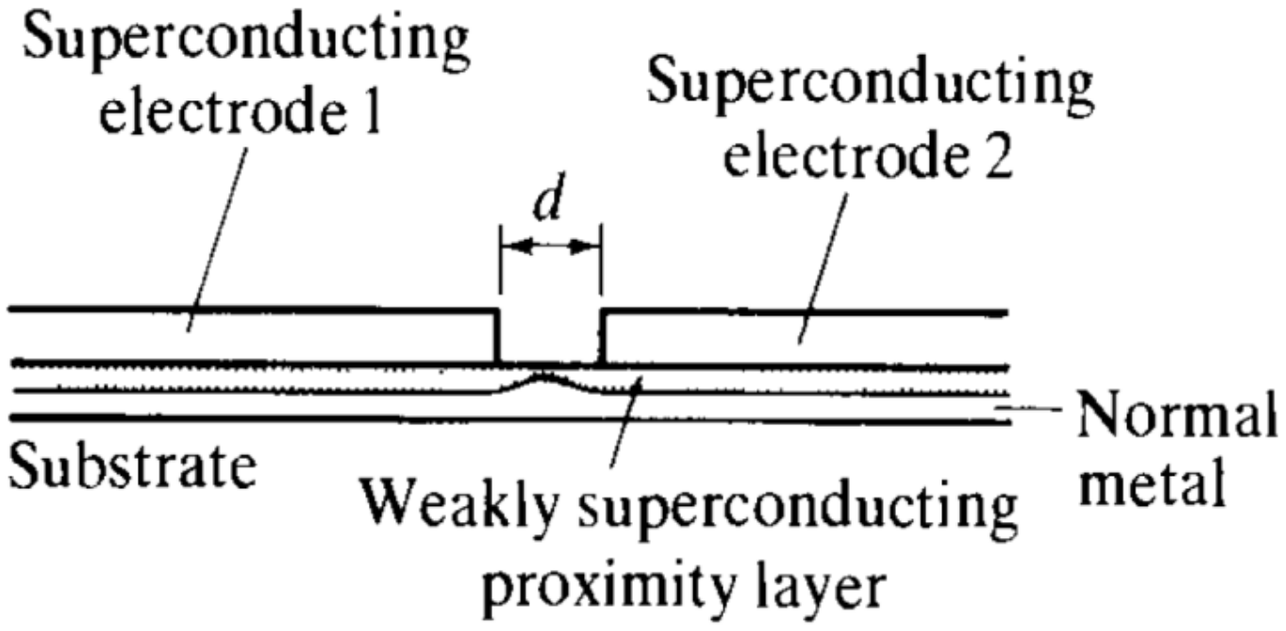
[2]*Quantum Matter Institute, University of British Columbia, Vancouver, BC, Canada V6T 1Z4*

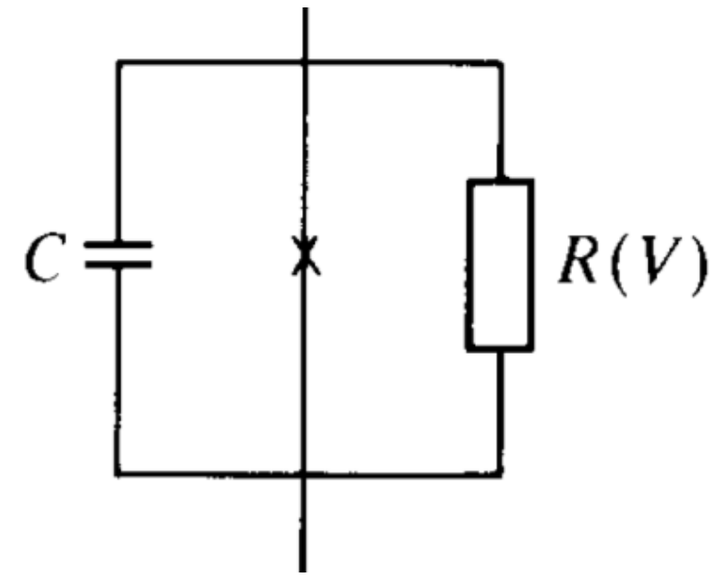
[3]*Station Q, Microsoft Research, Santa Barbara, California 93106-6105, USA*

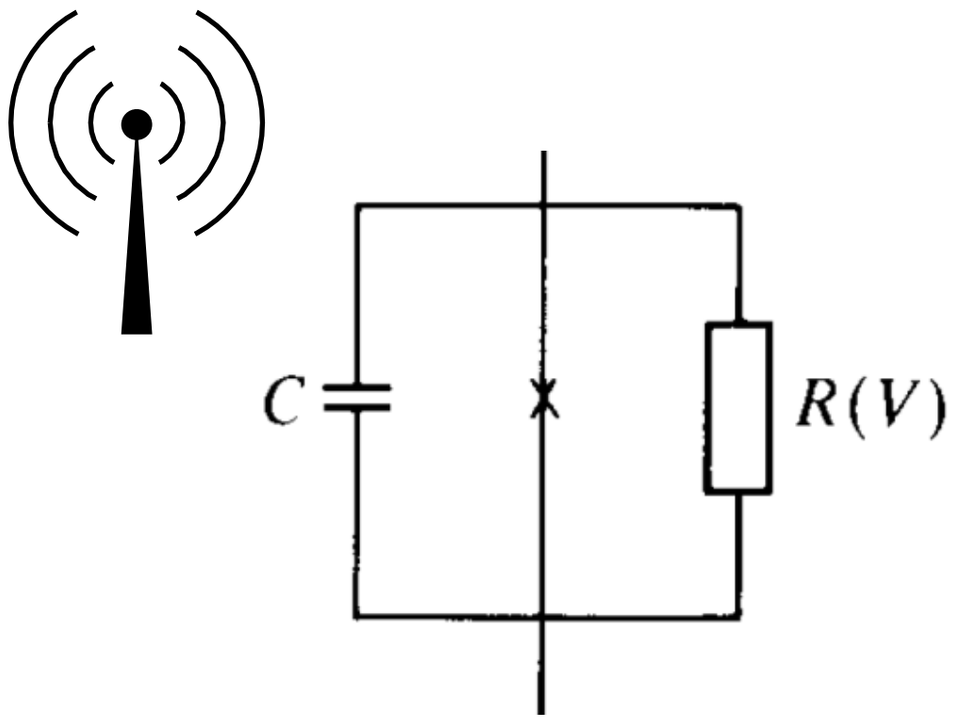
(Received 26 October 2016; revised manuscript received 13 March 2017; published 8 May 2017)

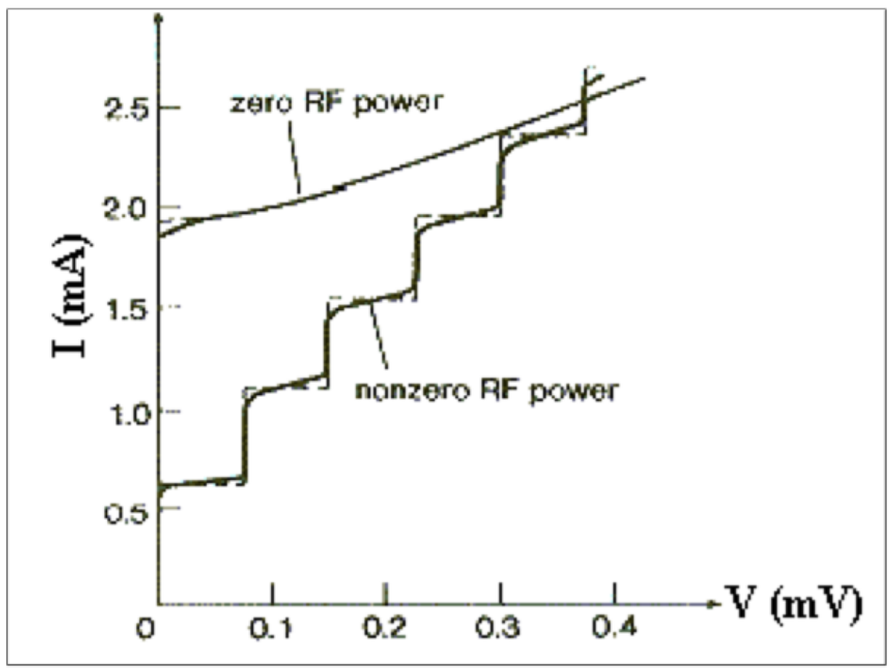
L. Balents, *Physics* **4**, 36 (2011)
X. Wan, A. M. Turner, A. Vishwanath, and S. Y. Savrasov, *Phys. Rev. B* **83**, 205101 (2011)

Shapiro Steps









$$V_n = n\frac{hf}{2e}$$

 Tinkham, M. (2004). Introduction to Superconductivity. Dover Publications. ISBN: 0486435032

PHYSICAL REVIEW LETTERS **120,** 177704 (2018)

π and 4π Josephson Effects Mediated by a Dirac Semimetal

W. Yu,[1] W. Pan,[1] D. L. Medlin,[2] M. A. Rodriguez,[1] S. R. Lee,[1] Zhi-qiang Bao,[3] and F. Zhang[3]
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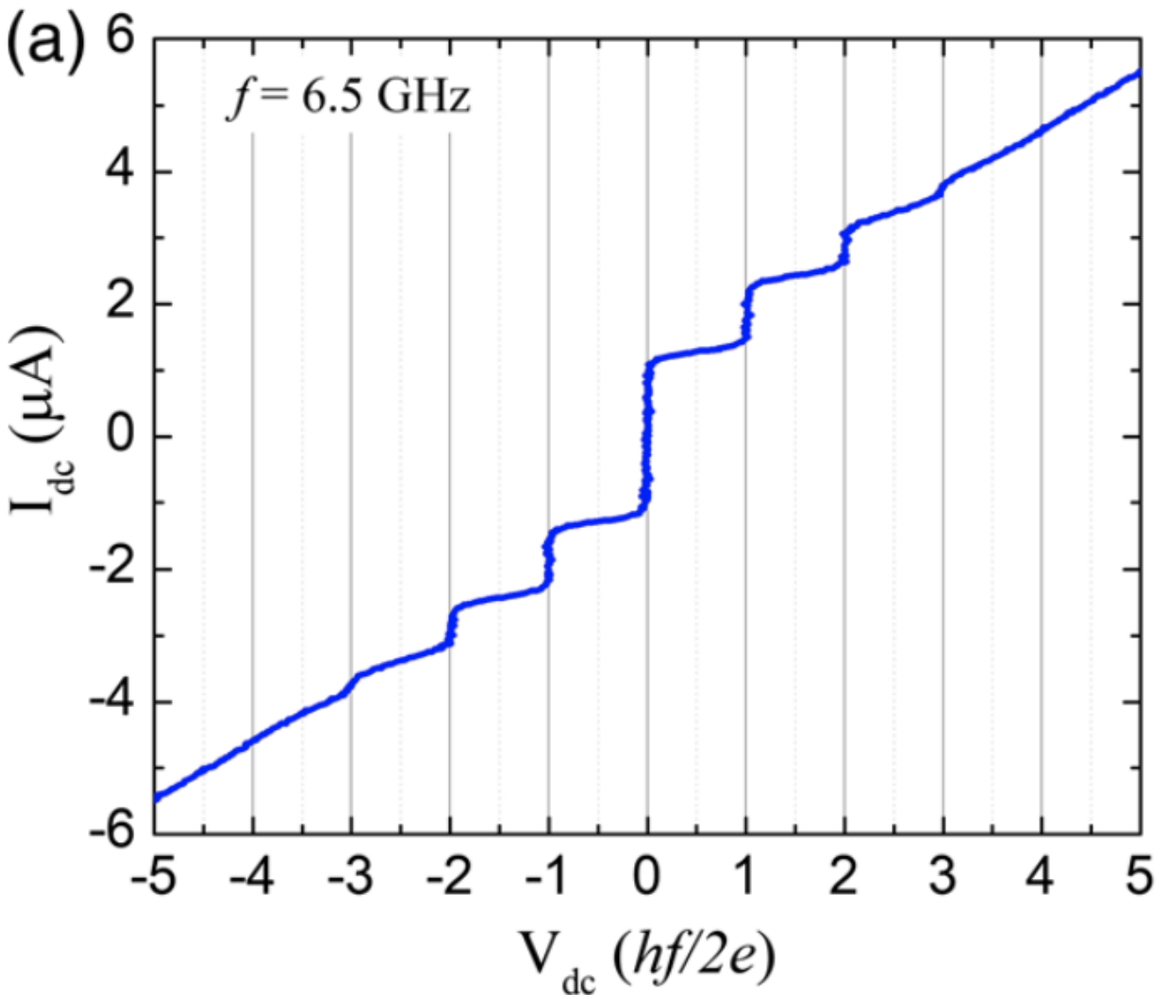
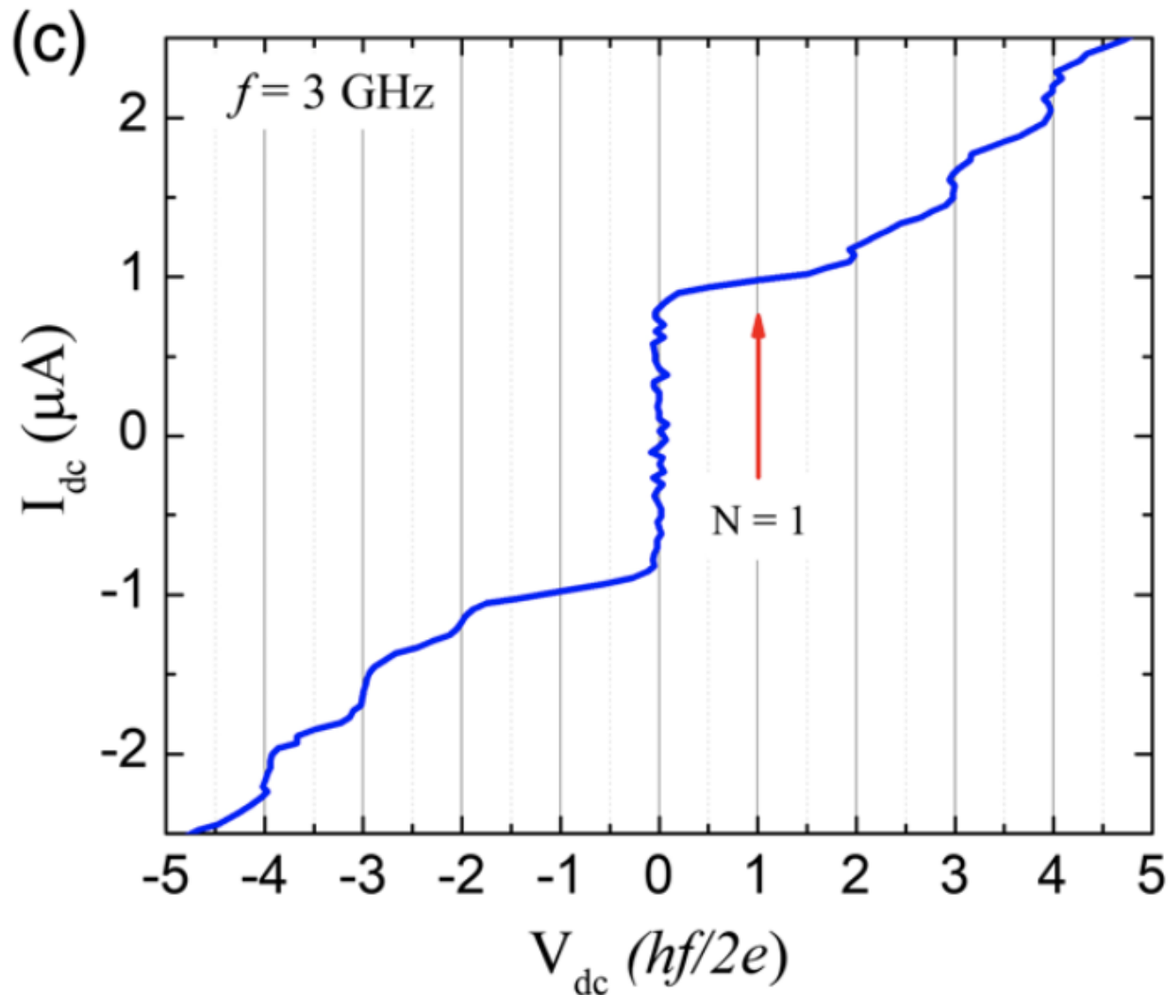
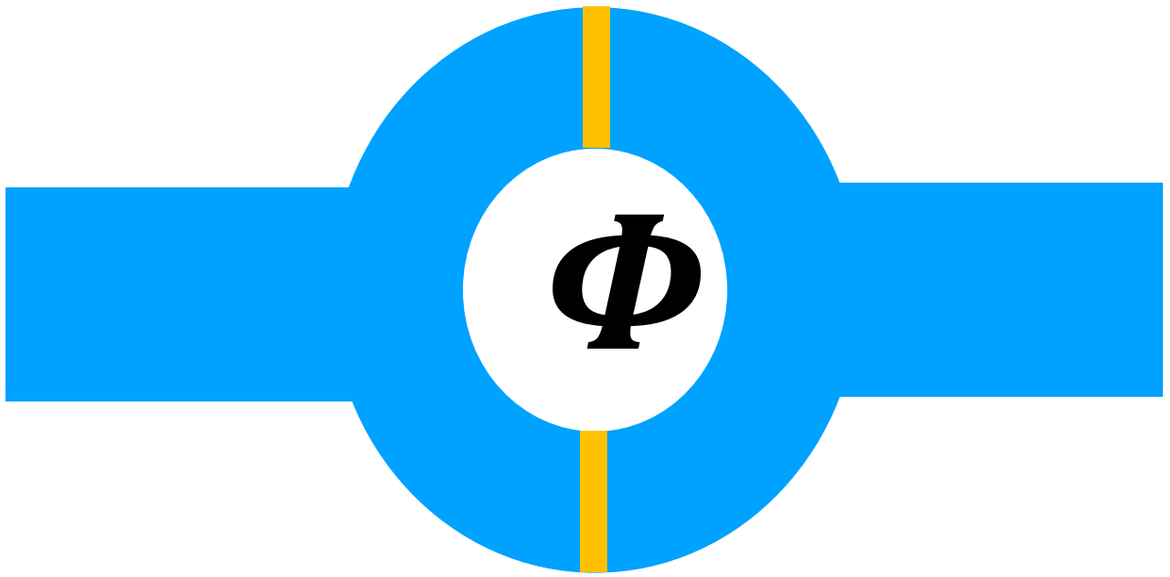
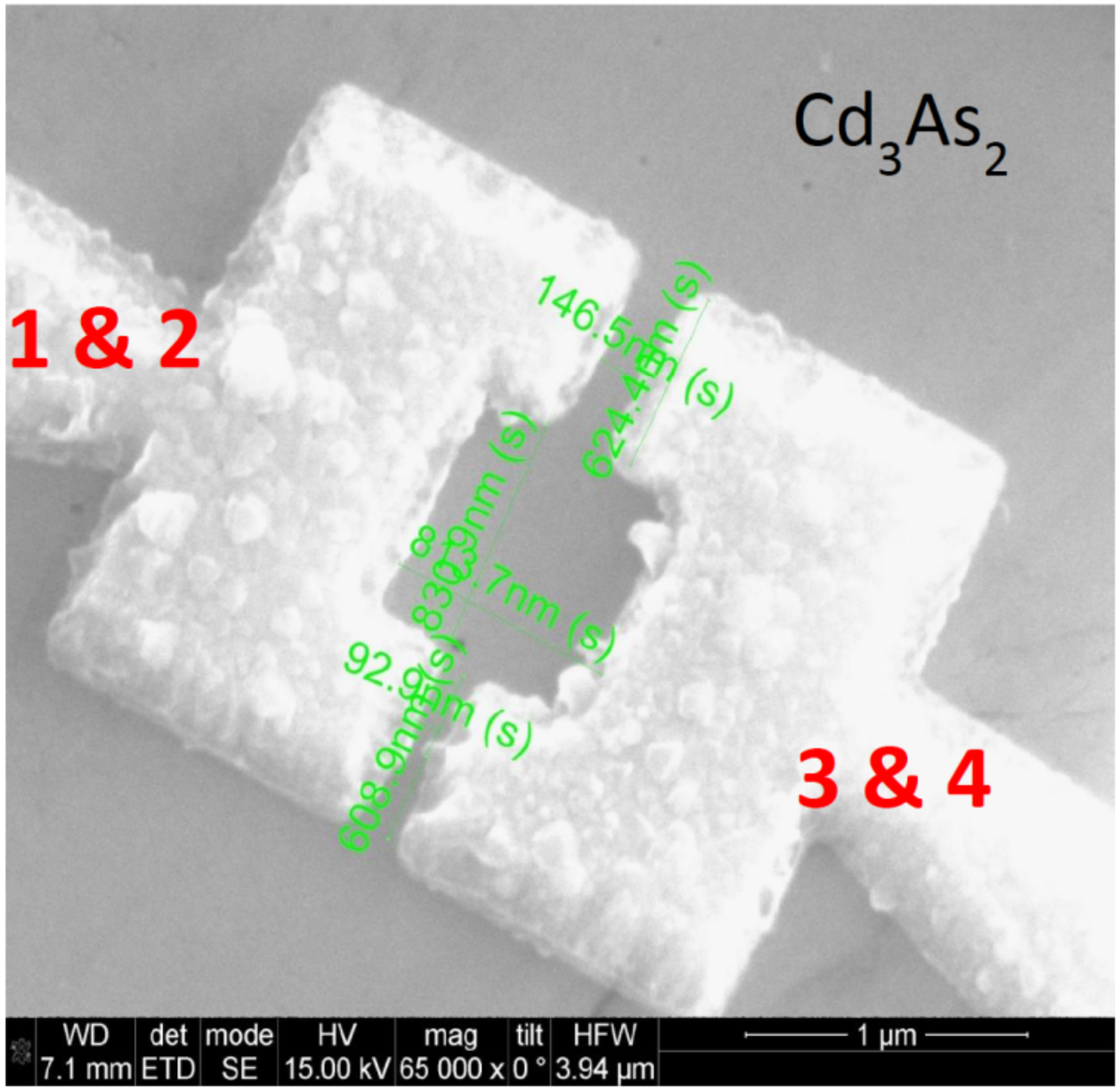
[3]*Department of Physics, University of Texas at Dallas, Dallas, Texas 75080, USA*

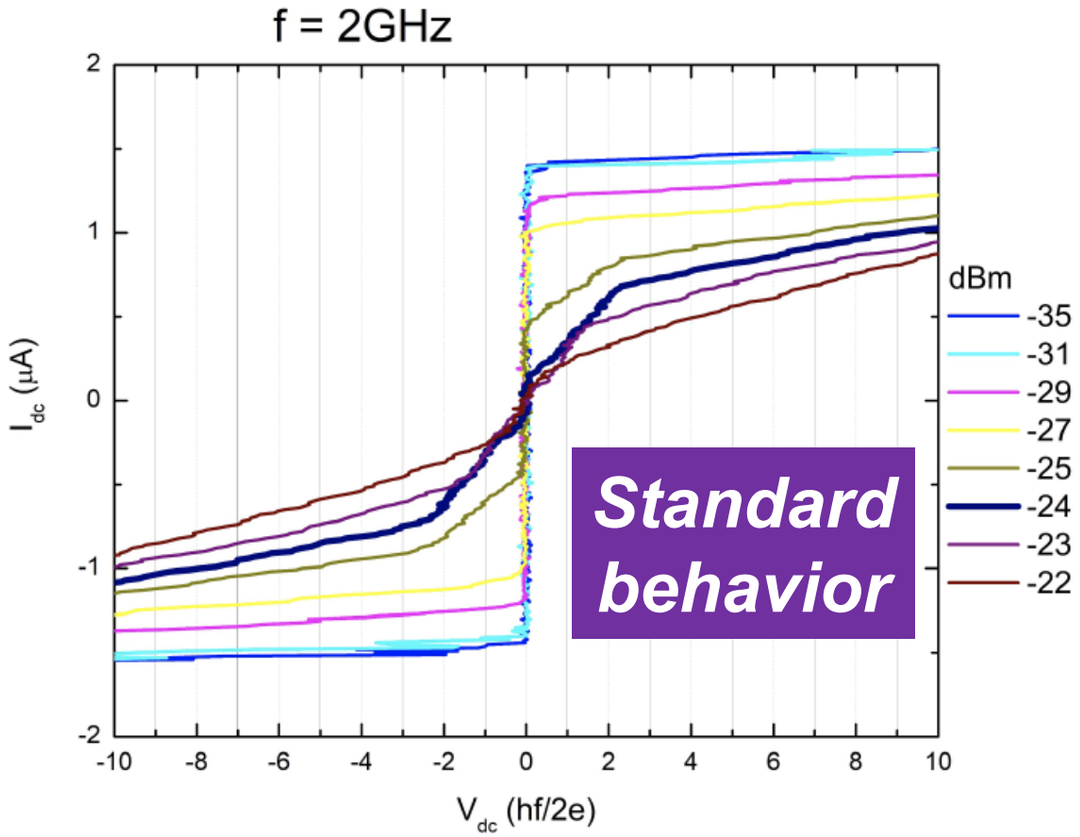


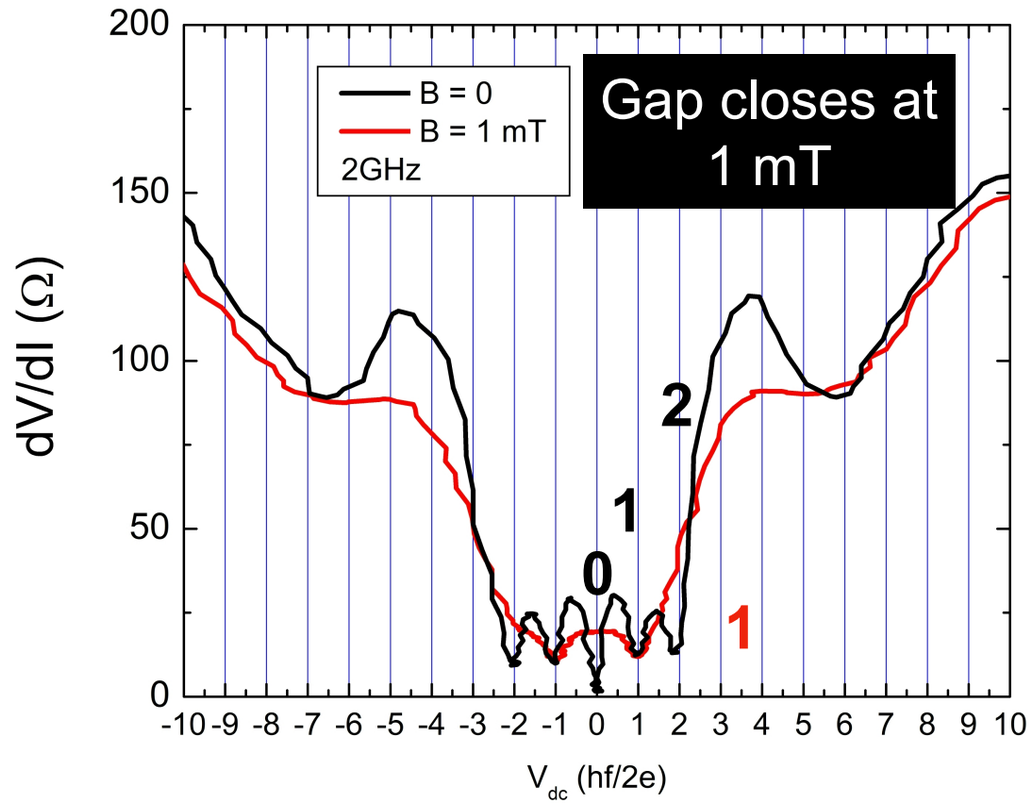


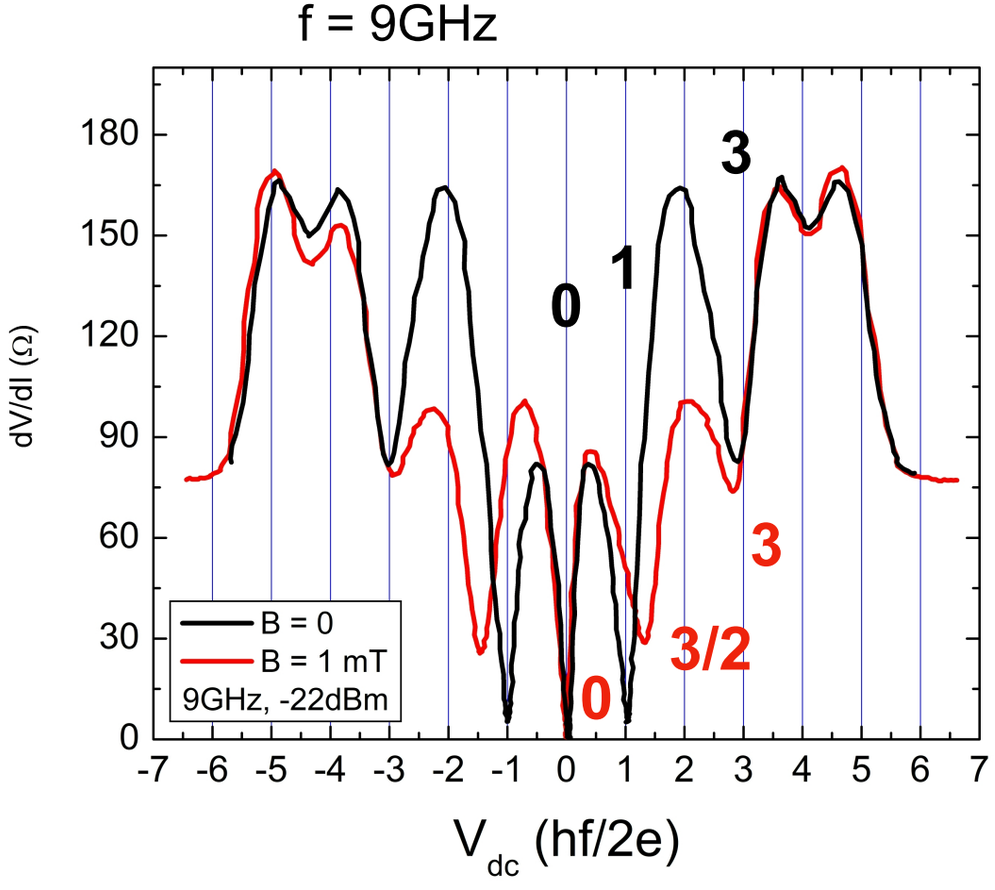
Cd3As2-based SQUID











Even steps are missing!

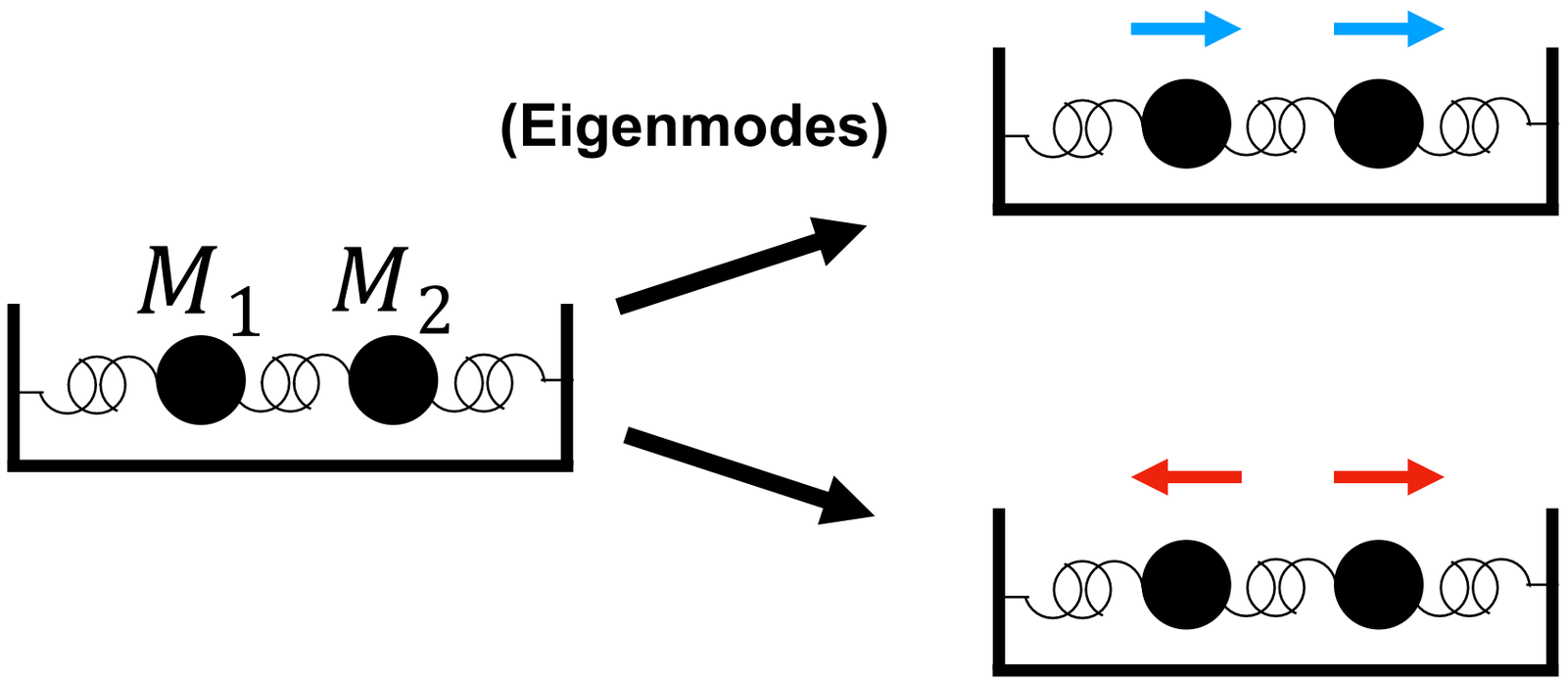
Fractional steps are observed

Gap is open at 0 ***and 1 mT***

Frequency dependent

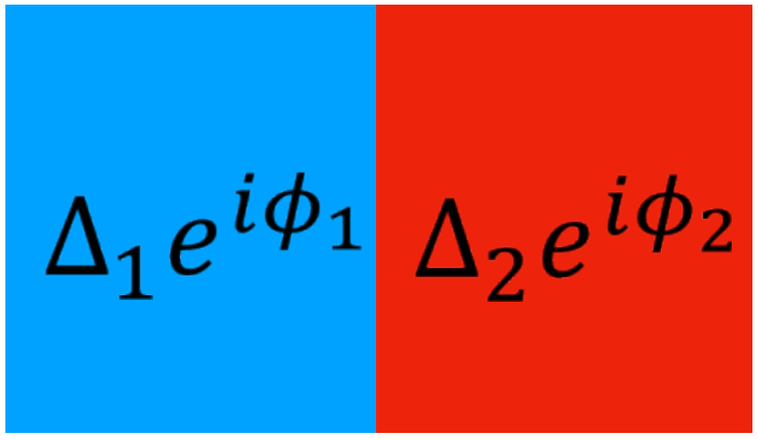
What is the origin of these anomalous features?

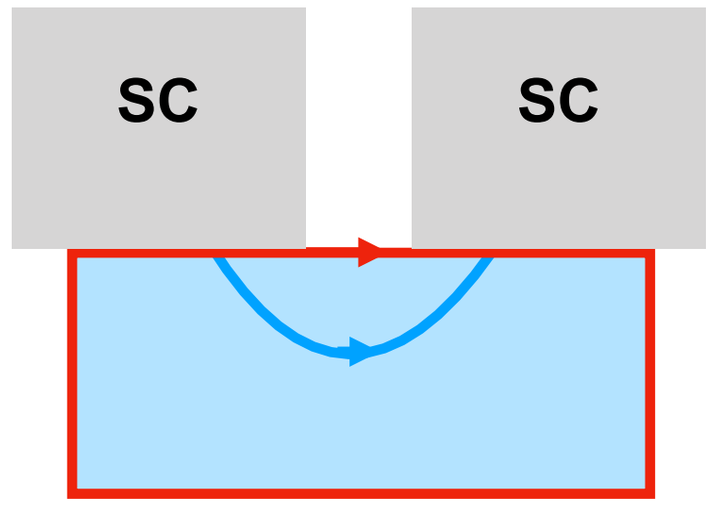
Josephson-Leggett Collective Mode



“Relative displacement” mode

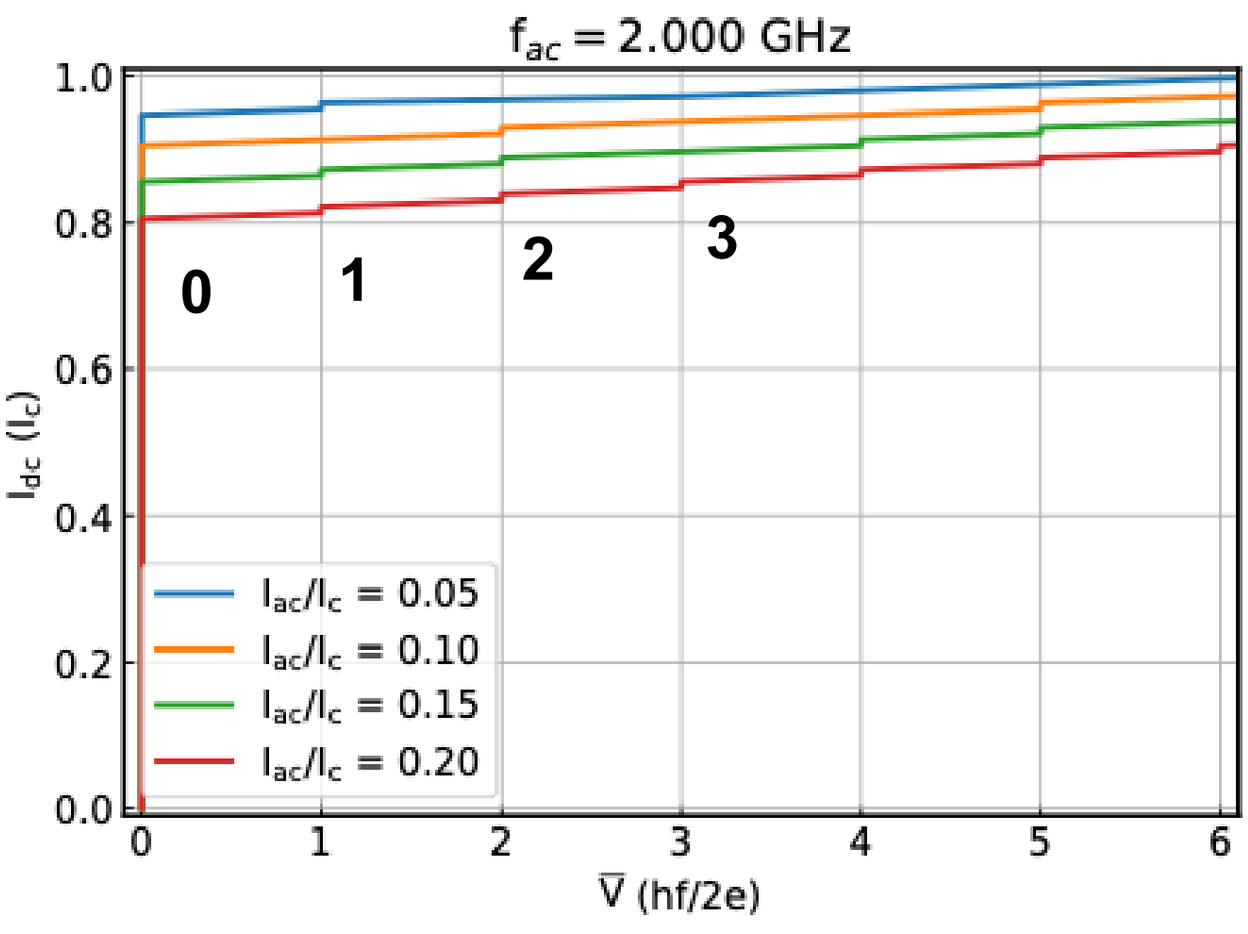
2-band superconductor

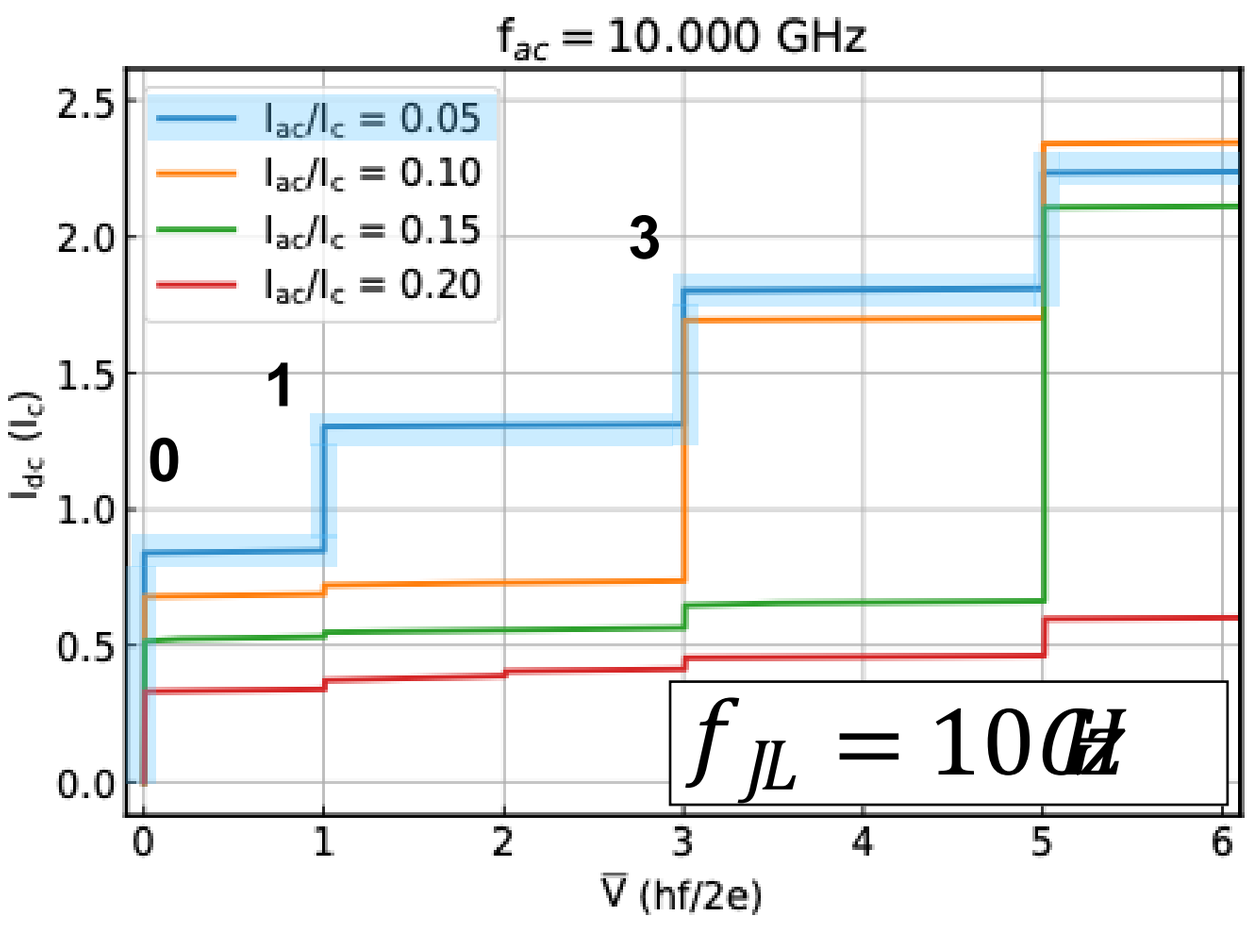


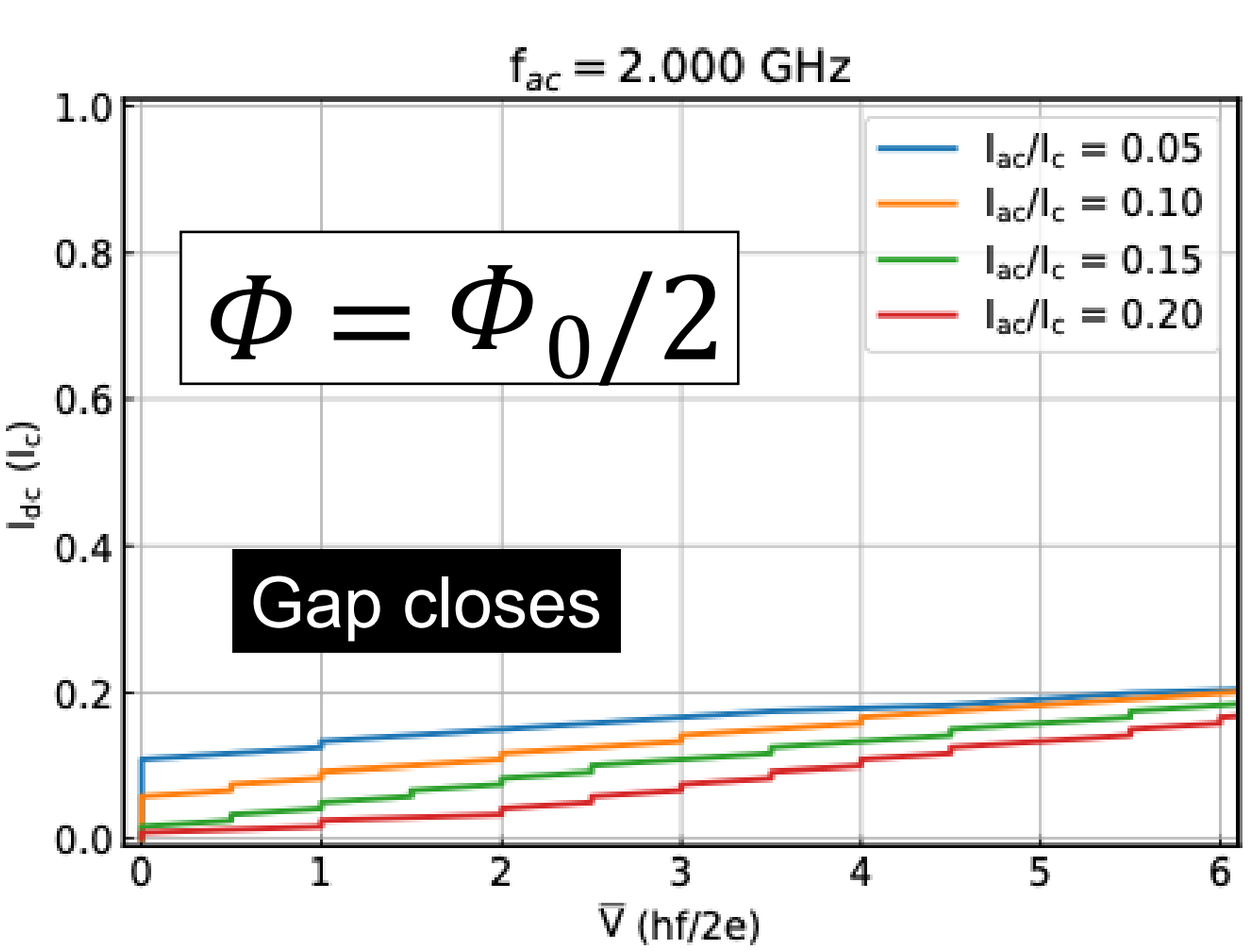


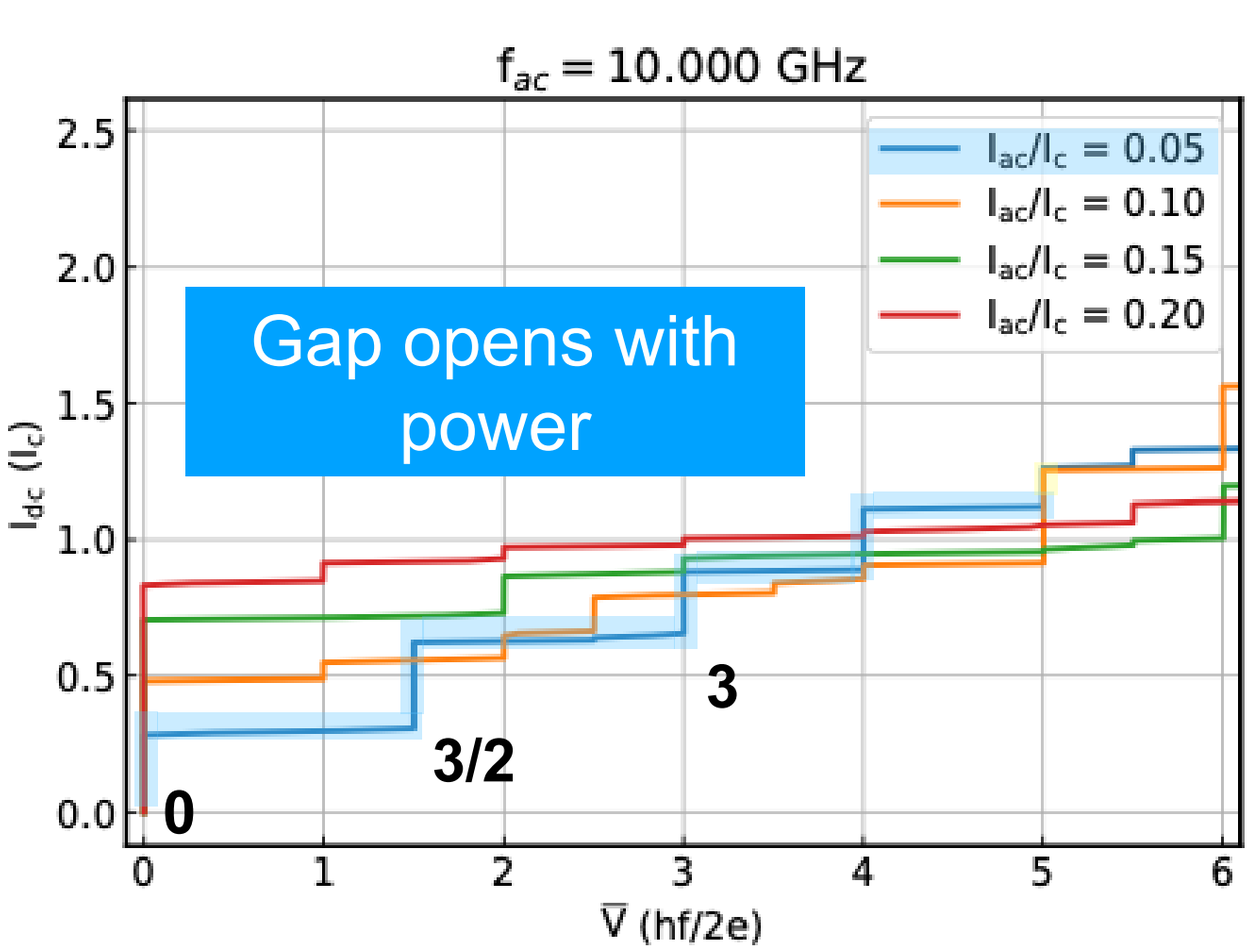
Surface and bulk channels in DSM

f_{JL}


$f_{ac} = 2.000$ GHz
I_{dc} (I_c)
$\bar{V}$ (hf/2e)
$I_{ac}/I_c = 0.05$
$I_{ac}/I_c = 0.10$
$I_{ac}/I_c = 0.15$
$I_{ac}/I_c = 0.20$
0
1
2
3


$f_{ac} = 10.000$ GHz
I_{dc} (I_c)
$\bar{V}$ (hf/2e)
$I_{ac}/I_c = 0.05$
$I_{ac}/I_c = 0.10$
$I_{ac}/I_c = 0.15$
$I_{ac}/I_c = 0.20$
0
1
3
$f_{JL} = 10$ GHz


$f_{ac} = 2.000$ GHz
$\Phi = \Phi_0/2$
Gap closes
I_{dc} (I_c)
$\bar{V}$ (hf/2e)
$I_{ac}/I_c = 0.05$
$I_{ac}/I_c = 0.10$
$I_{ac}/I_c = 0.15$
$I_{ac}/I_c = 0.20$


$f_{ac} = 10.000$ GHz
Gap opens with power
I_{dc} (I_c)
$\bar{V}$ (hf/2e)
$I_{ac}/I_c = 0.05$
$I_{ac}/I_c = 0.10$
$I_{ac}/I_c = 0.15$
$I_{ac}/I_c = 0.20$
0
3/2
3

Summary

- We observe anomalous Shapiro steps in Dirac semimetal (DSM) Cd3As2-based SQUID
- We attribute the anomalous features to a Josephson-Leggett (JL) collective mode in our device
- The first observation of a JL mode (to our knowledge)
  - Standard Leggett modes: rare in nature
- Novel realization in a DSM
  - Opens a new door to explore topological superconductivity and high-temperature superconductivity

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