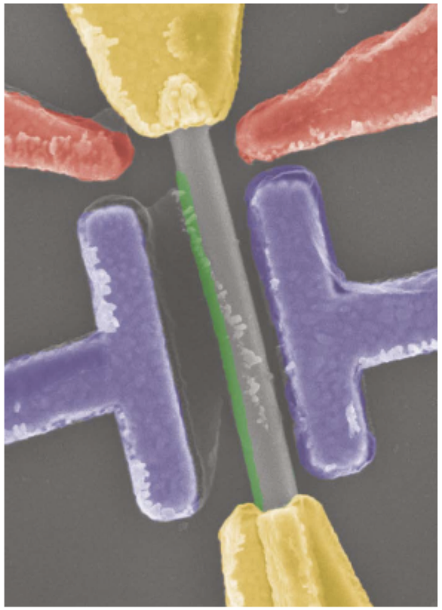
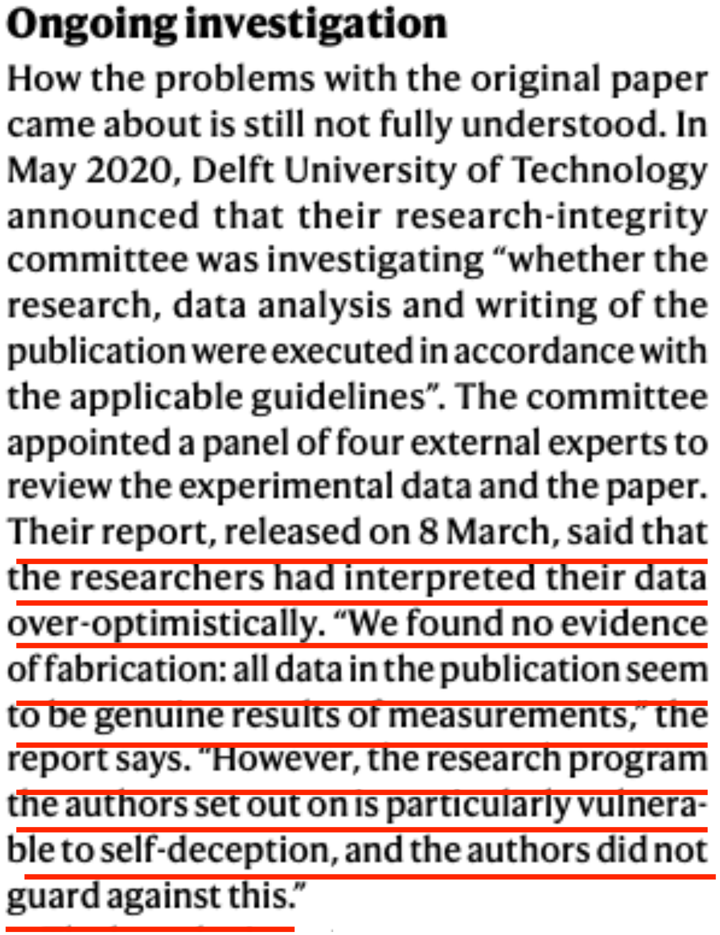
EVIDENCE OF ELUSIVE MAJORANA PARTICLE DIES WITH RETRACTION

But search for exotic states lives on, despite setback for Microsoft's approach to quantum computing.

354 | Nature | Vol 591 | 18 March 2021



A nanowire (green) that was used to try to create Majorana fermions.



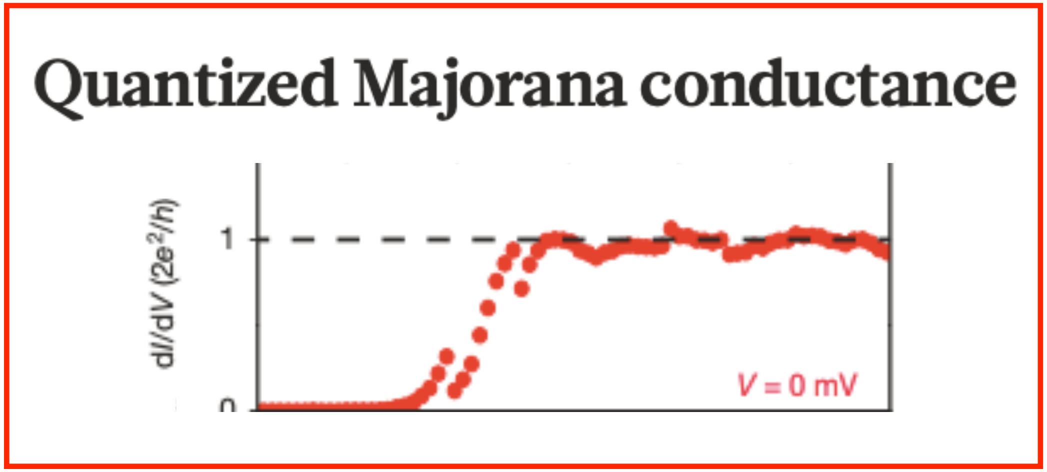
Ongoing investigation

How the problems with the original paper came about is still not fully understood. In May 2020, Delft University of Technology announced that their research-integrity committee was investigating "whether the research, data analysis and writing of the publication were executed in accordance with the applicable guidelines". The committee appointed a panel of four external experts to review the experimental data and the paper. Their report, released on 8 March, said that the researchers had interpreted their data over-optimistically. "We found no evidence of fabrication: all data in the publication seem to be genuine results of measurements," the report says. "However, the research program the authors set out on is particularly vulnerable to self-deception, and the authors did not guard against this."

?????

The Recent Majorana Saga/Retraction

I. The 2018 Excitement


Quantized Majorana conductance

Background

The Majorana “Recipe”

Observation of Quantized Majorana States

II. The 2021 Retraction

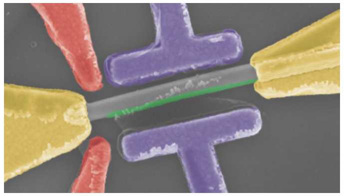
Major(ana) Backpedaling: Microsoft-Backed Quantum Computer Research Retracted

Controversial evidence for elusive, hypothesized quasiparticles debunked

Questions

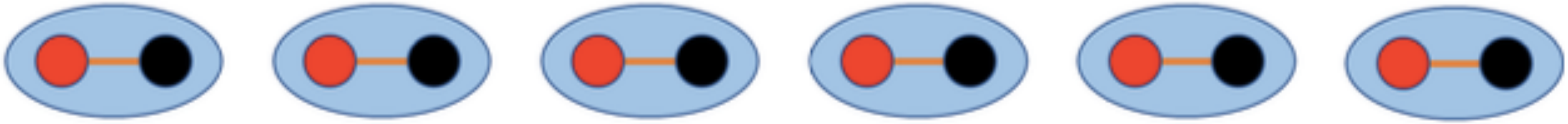
Observation of Almost Quantized Non-Majorana States

A Revised Approach to the 2018 Data



What’s Next ??

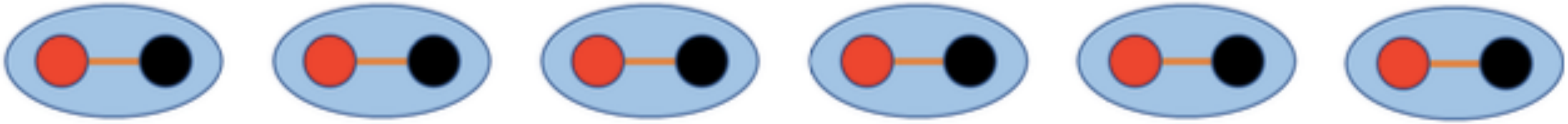
Kitaev Toy Model



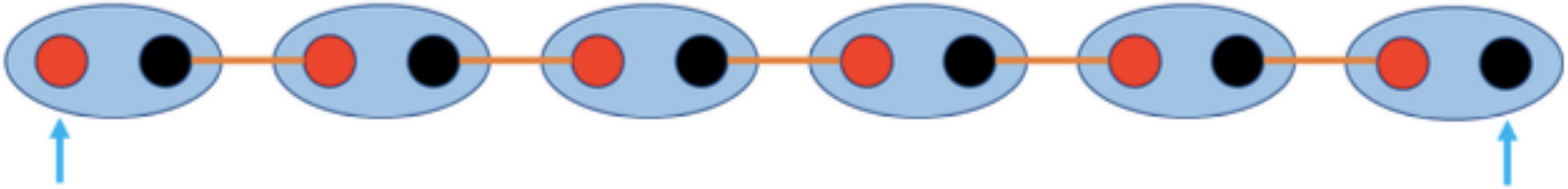
Majoranas on same sites are coupled

A.Y. Kitaev, Unpaired Majorana Fermions in Quantum Wires, Physics Uspekhi (2001)

Kitaev Toy Model



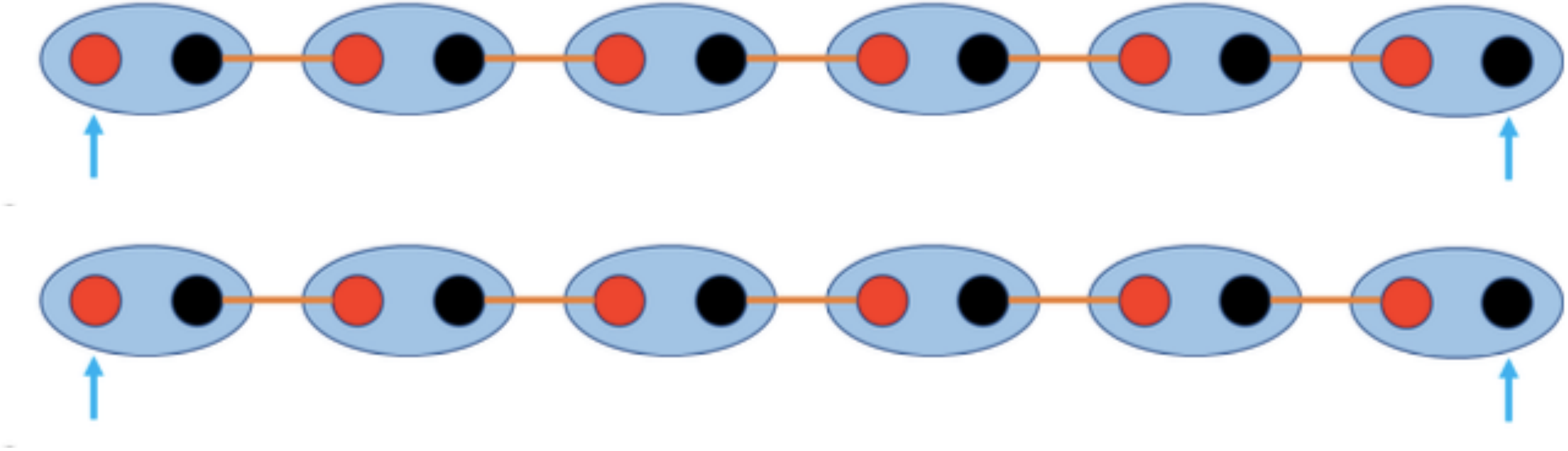
Majoranas on same sites are coupled



Tunnel coupling pairs Majoranas on different sites

A.Y. Kitaev, Unpaired Majorana Fermions in Quantum Wires, Physics Uspekhi (2001)

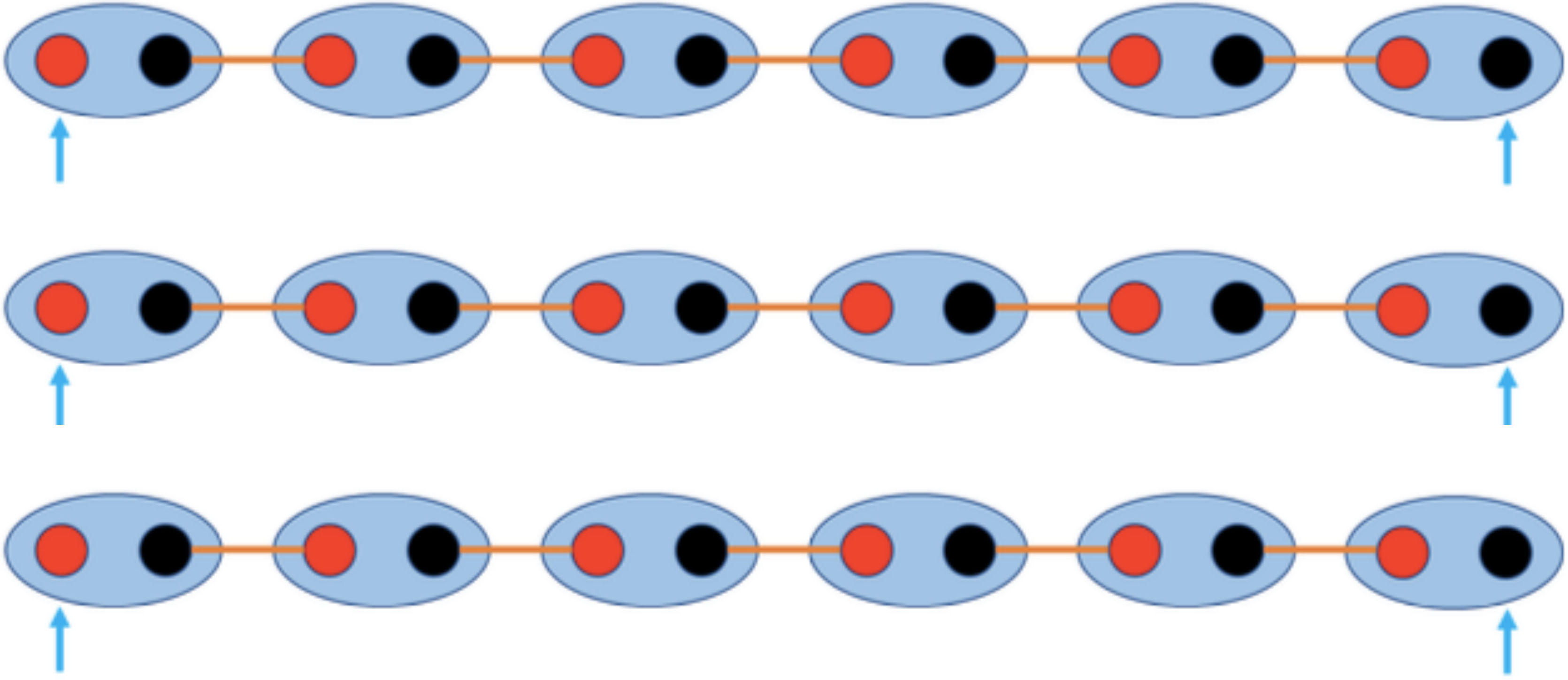
Kitaev Toy Model



A.Y. Kitaev, Unpaired Majorana Fermions in Quantum Wires, Physics Uspekhi (2001)

Kitaev Toy Model

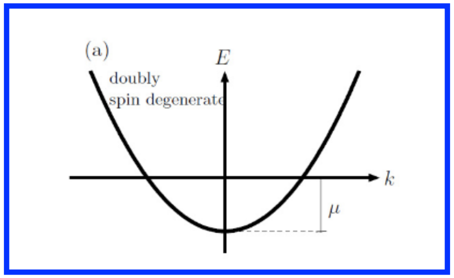
Need Odd Number of Chains !!

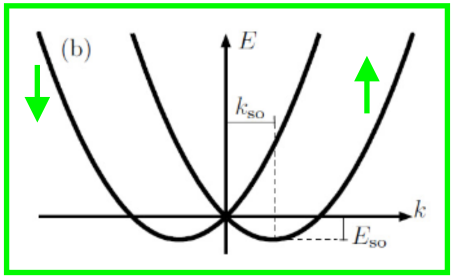


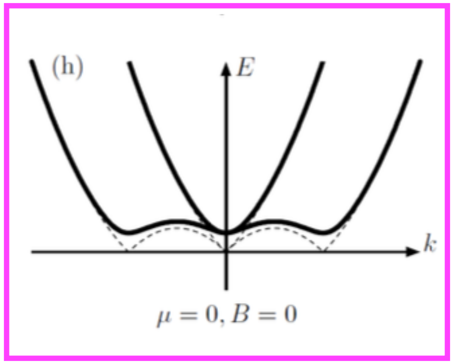
A.Y. Kitaev, Unpaired Majorana Fermions in Quantum Wires, Physics Uspekhi (2001)

Majorana Recipe

1. One-Dimensional Wire
2. Spin-Orbit Interaction
3. Superconductivity
4. Magnetism (Field or Ferromagnetism)

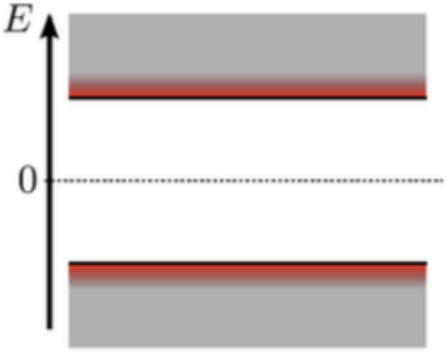




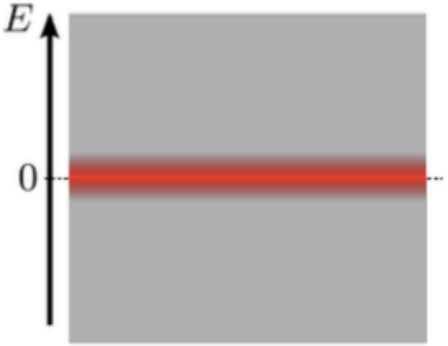


Topological Superconductor !!

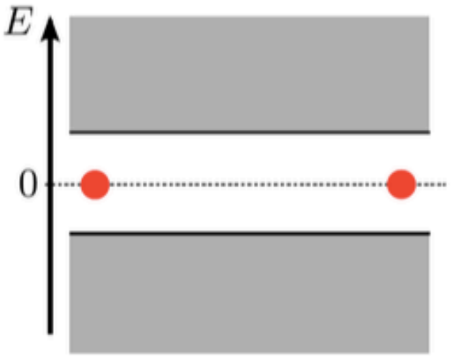
Lutchyn, Sau, Das Sarma, PRL (2010)
Oreg, Rafael, von Oppen, PRL (2010)



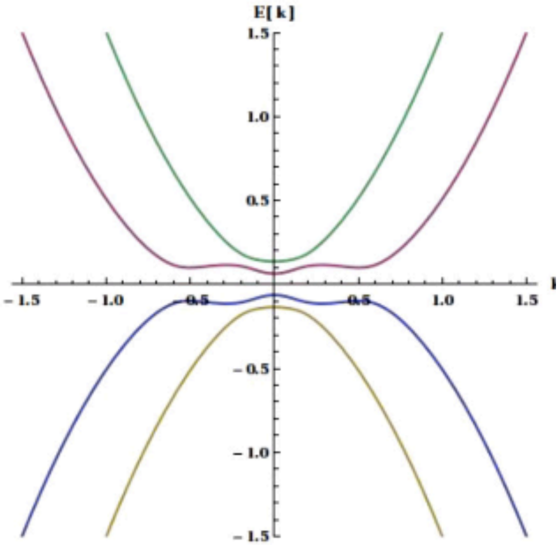
$E_Z < \Delta$



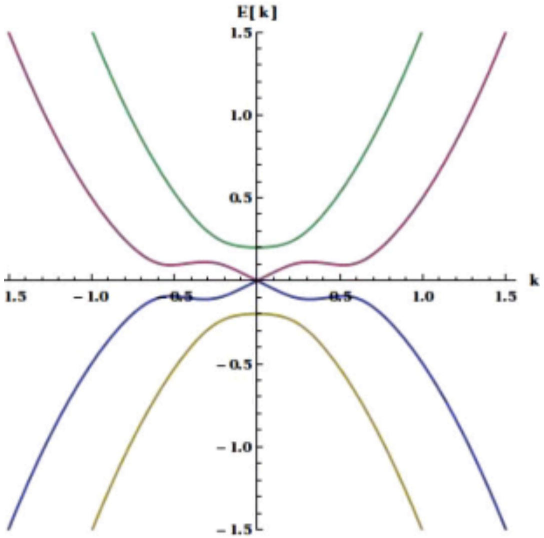
$E_Z = \Delta$



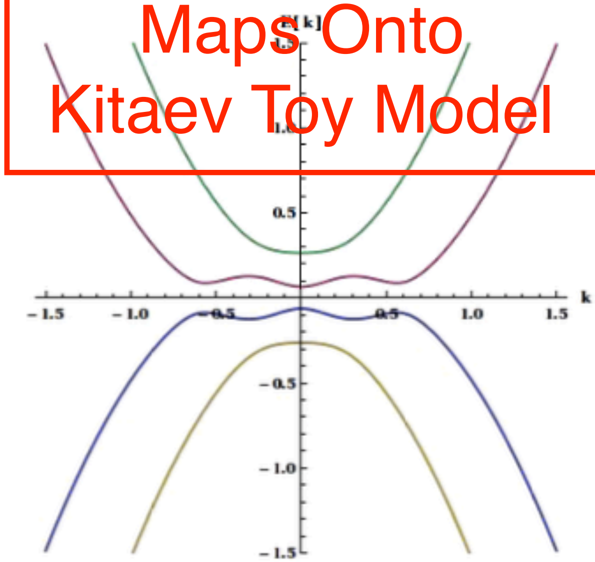
$E_Z > \Delta$



Trivial Superconductor
"positive gap"



Majorana
"zero gap"

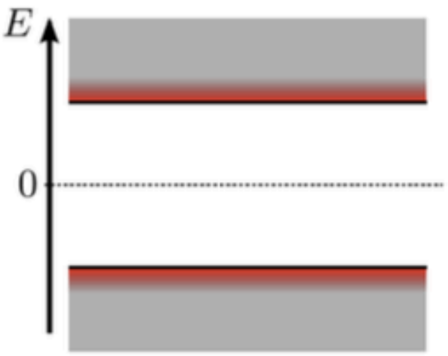


Maps Onto
Kitaev Toy Model

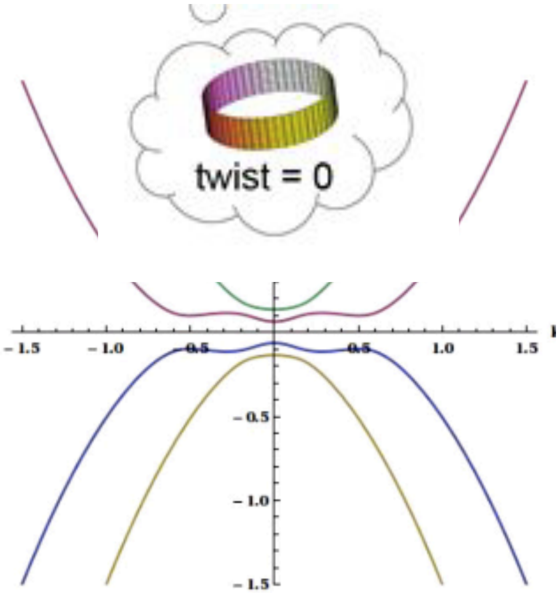
Topological Superconductor
"negative gap"

Topology: A Geometric Property that Cannot be Changed by Continuous Deformations

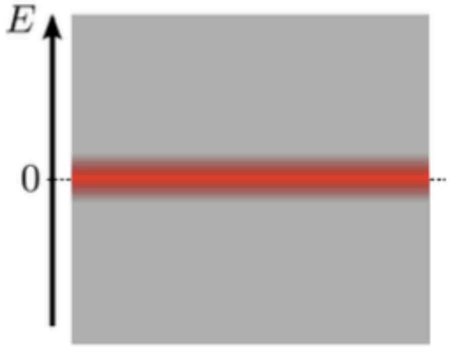
Requires Topological Phase Transition



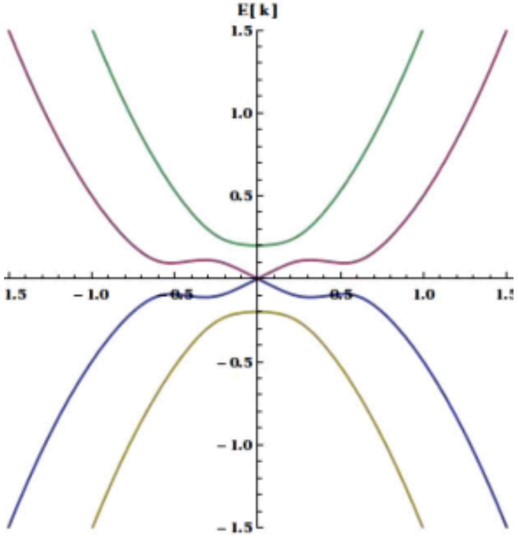
$E_Z < \Delta$



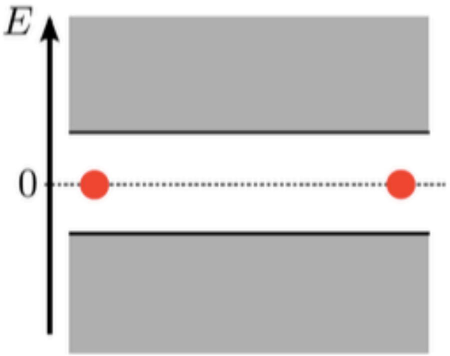
Trivial Superconductor
"positive gap"



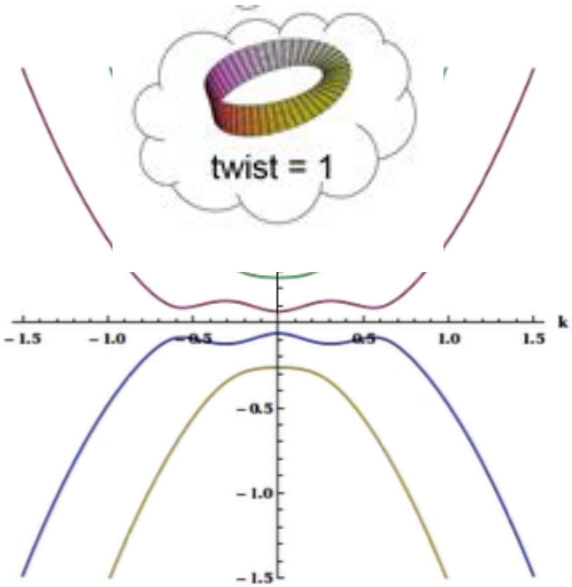
$E_Z = \Delta$



Majorana
"zero gap"



$E_Z > \Delta$



Topological Superconductor
"negative gap"

How to Detect these Majoranas?

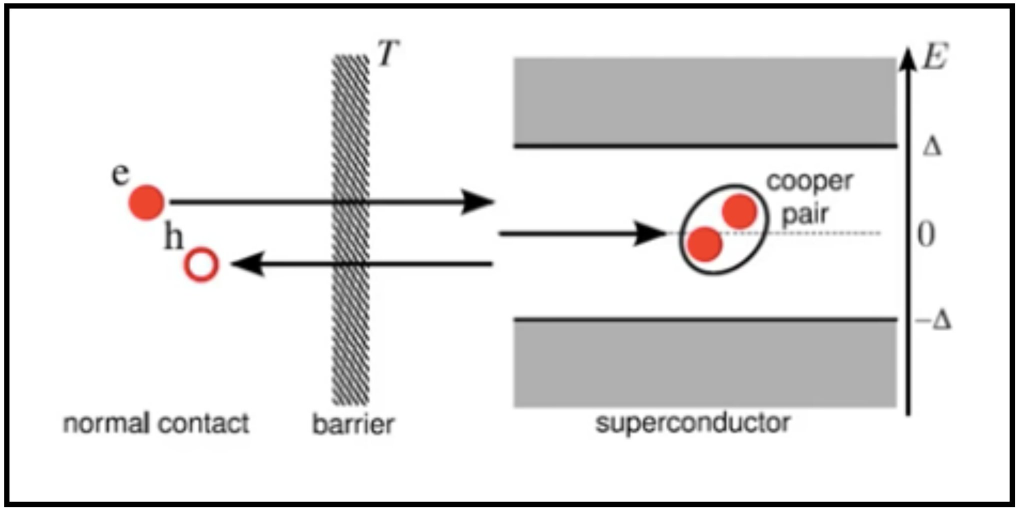
Chargeless !

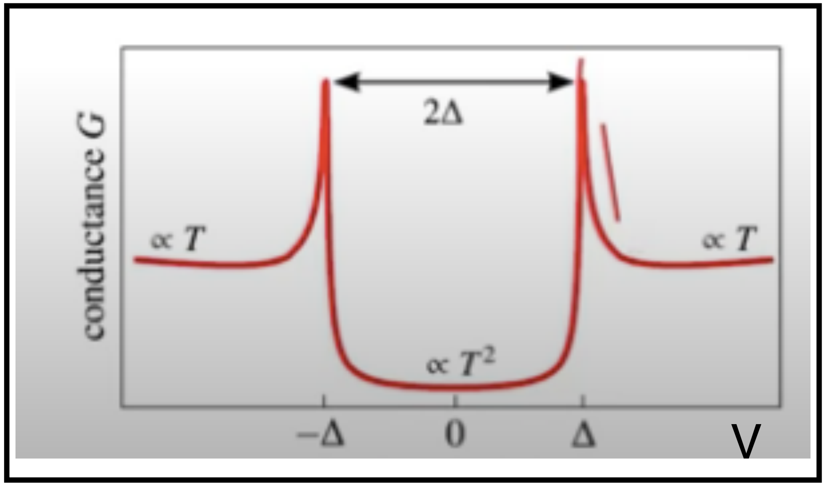
Spinless !

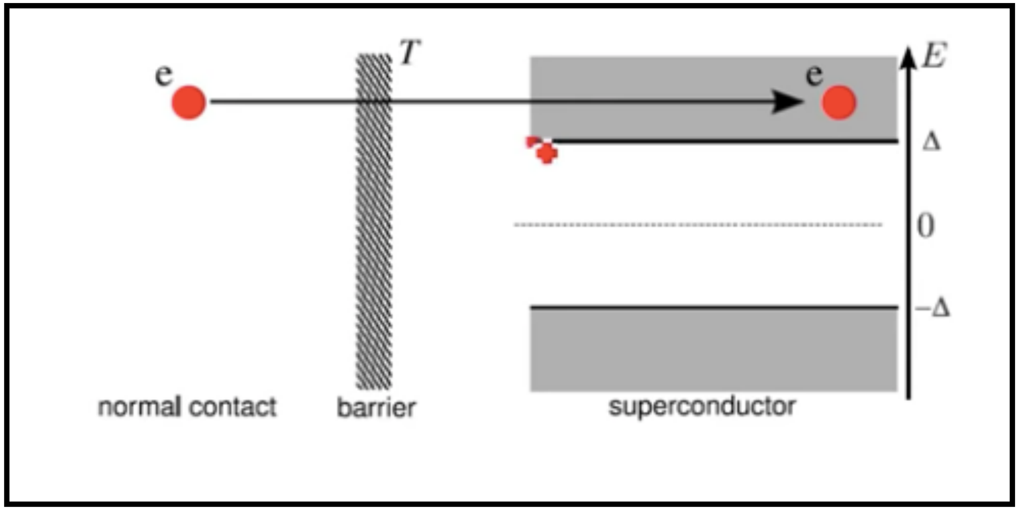
Massless !

Andreev Reflection

(Conventional Superconductor)



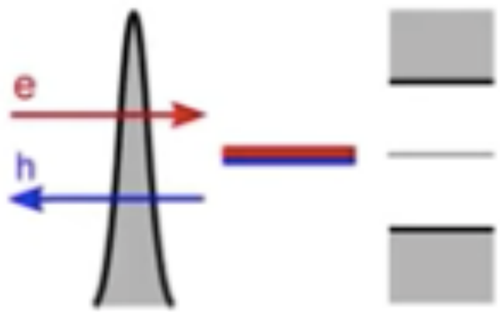


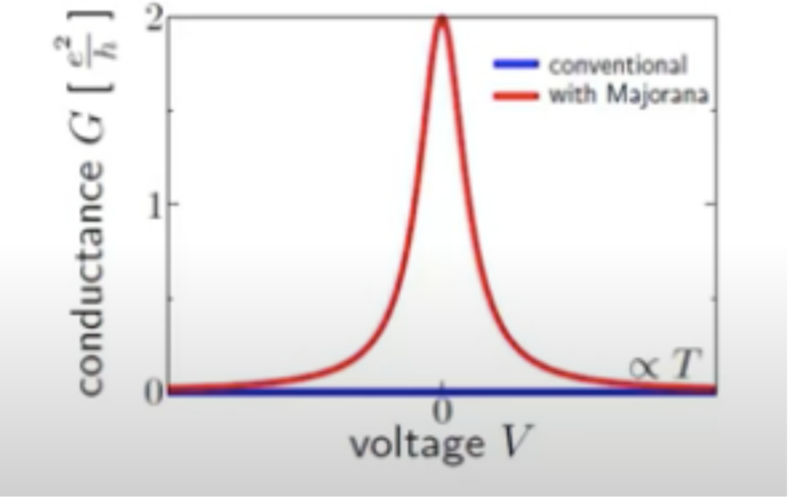


Andreev Transport
Spectrum is
a Probe of the
Superconducting Gap

Majorana Resonance

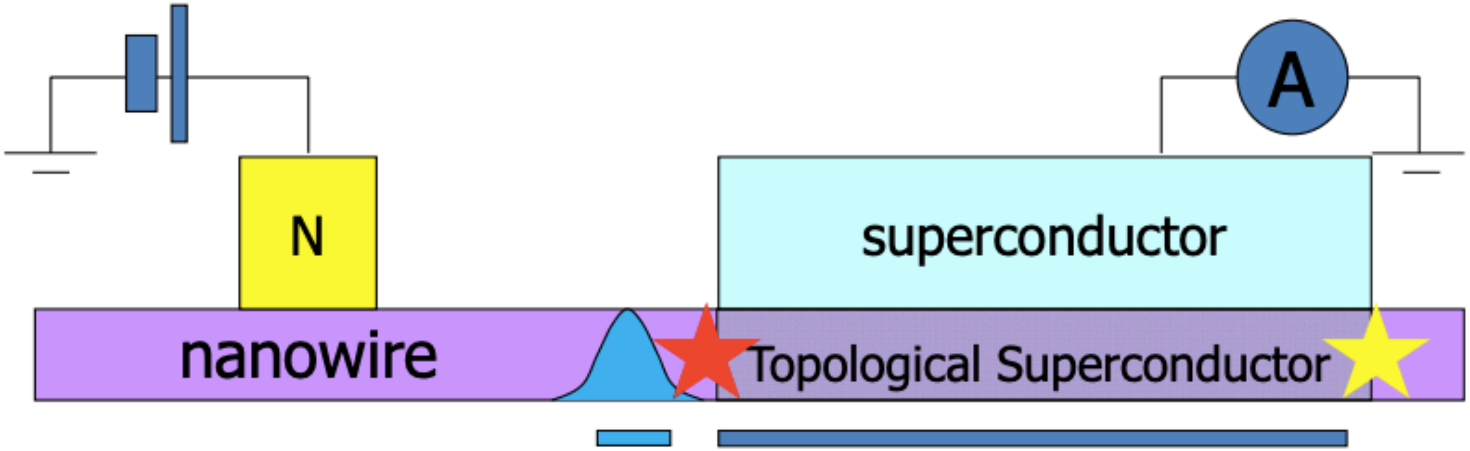
Tunnel Andreev Spectroscopy



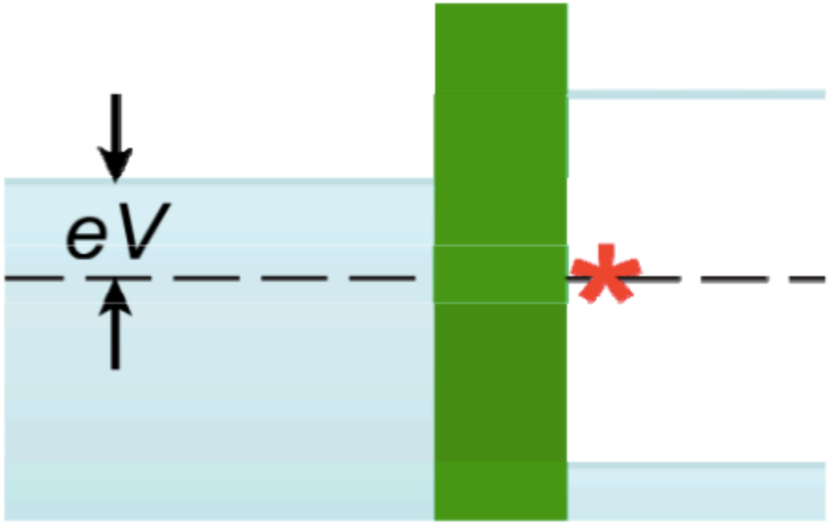


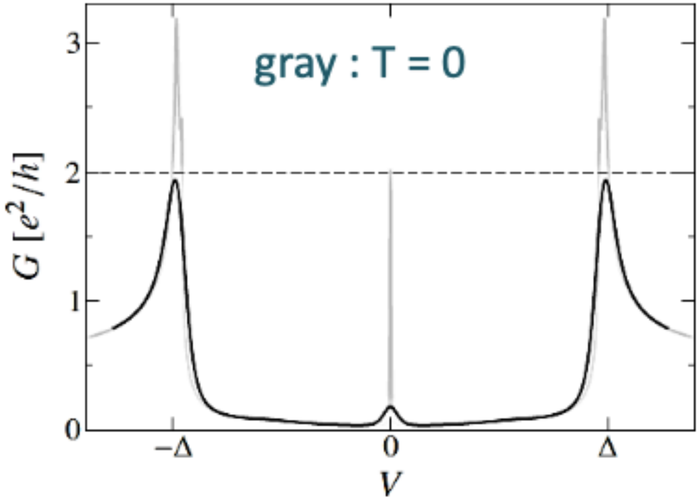
Majorana leads to Quantized Conductance !!

Tunneling experiment



Tunneling into a Majorana bound state:
Resonant Andreev current!





Which nanowire? Which superconductor?

Need:
- strong spin-orbit coupling
- large g-factor
- ballistic 1D transport

InAs nanowires:

g = 6-10, lso=100 nm
Disorder is high (low mobility)

InSb nanowires:

Larger g, similar lso, “cleaner”

Need:
- large gap
- withstand high B-fields
- small work function mismatch

Aluminum contacts:

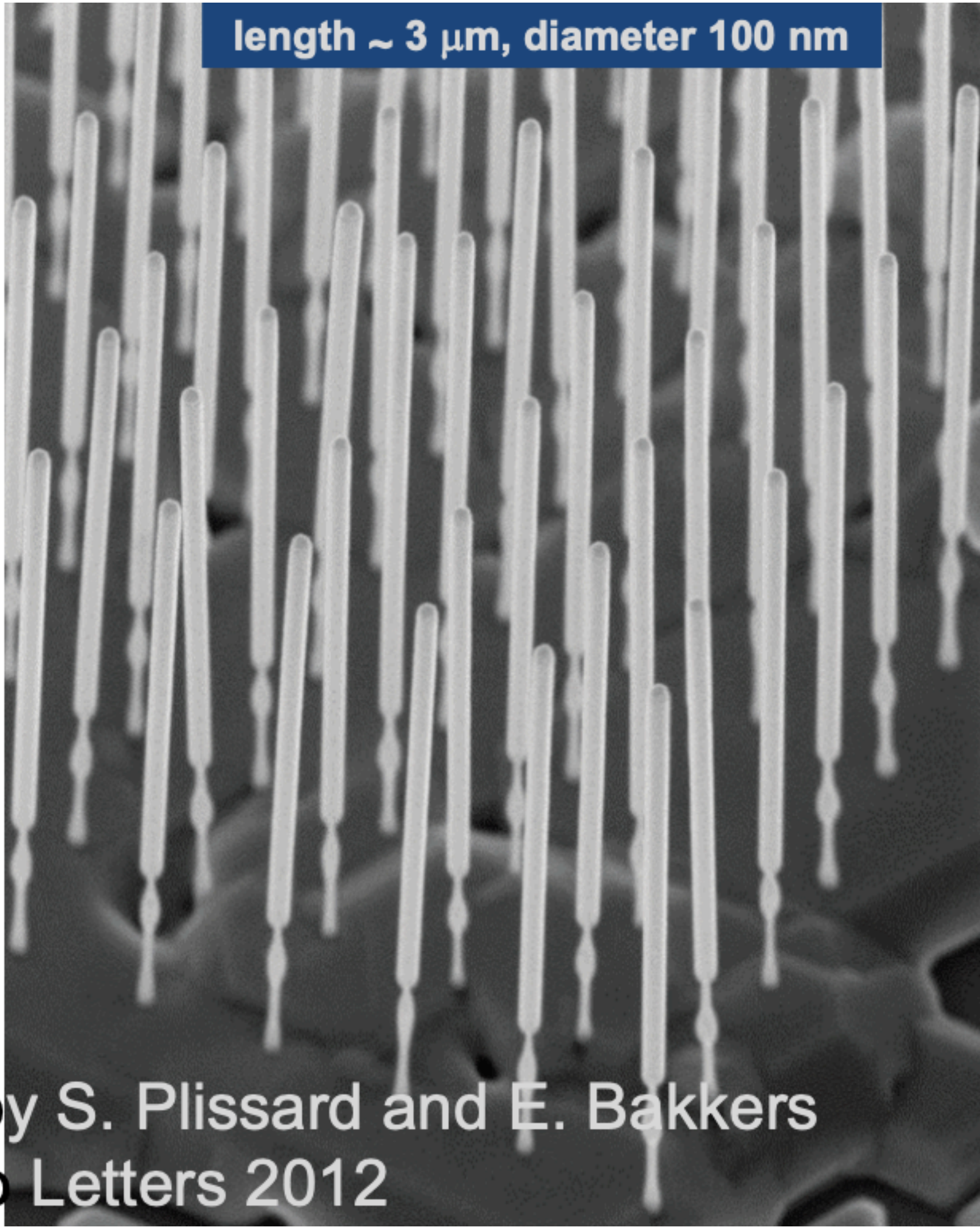
Gap ~ 100 ueV
Critical field ~100 mT

NbTiN contacts:

Gap ~ 3meV
Critical field > 10 T

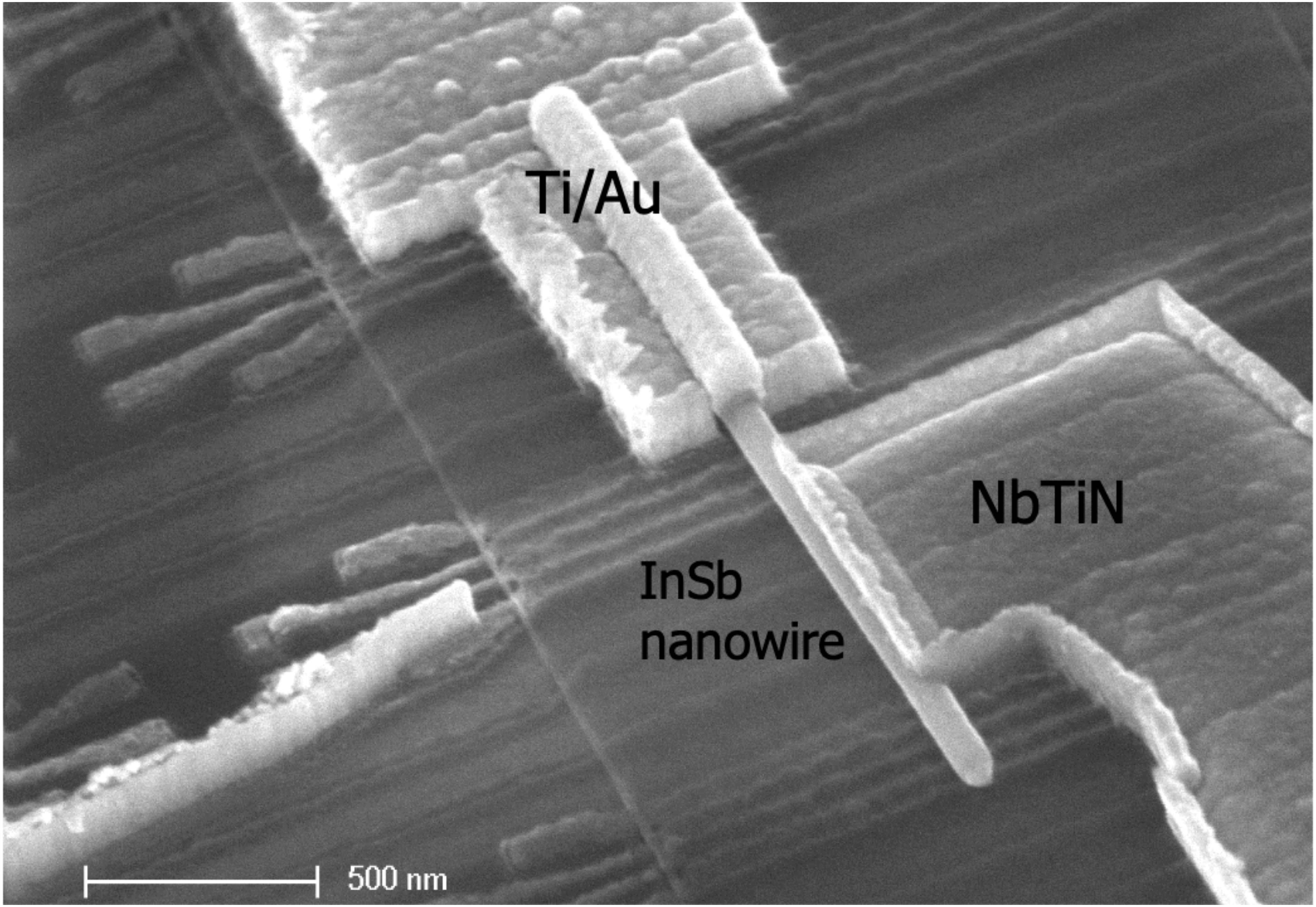
Why InSb?

1) High mobility
2) Large spin-orbit
3) Large g-factor
4) Easy ohmic contact

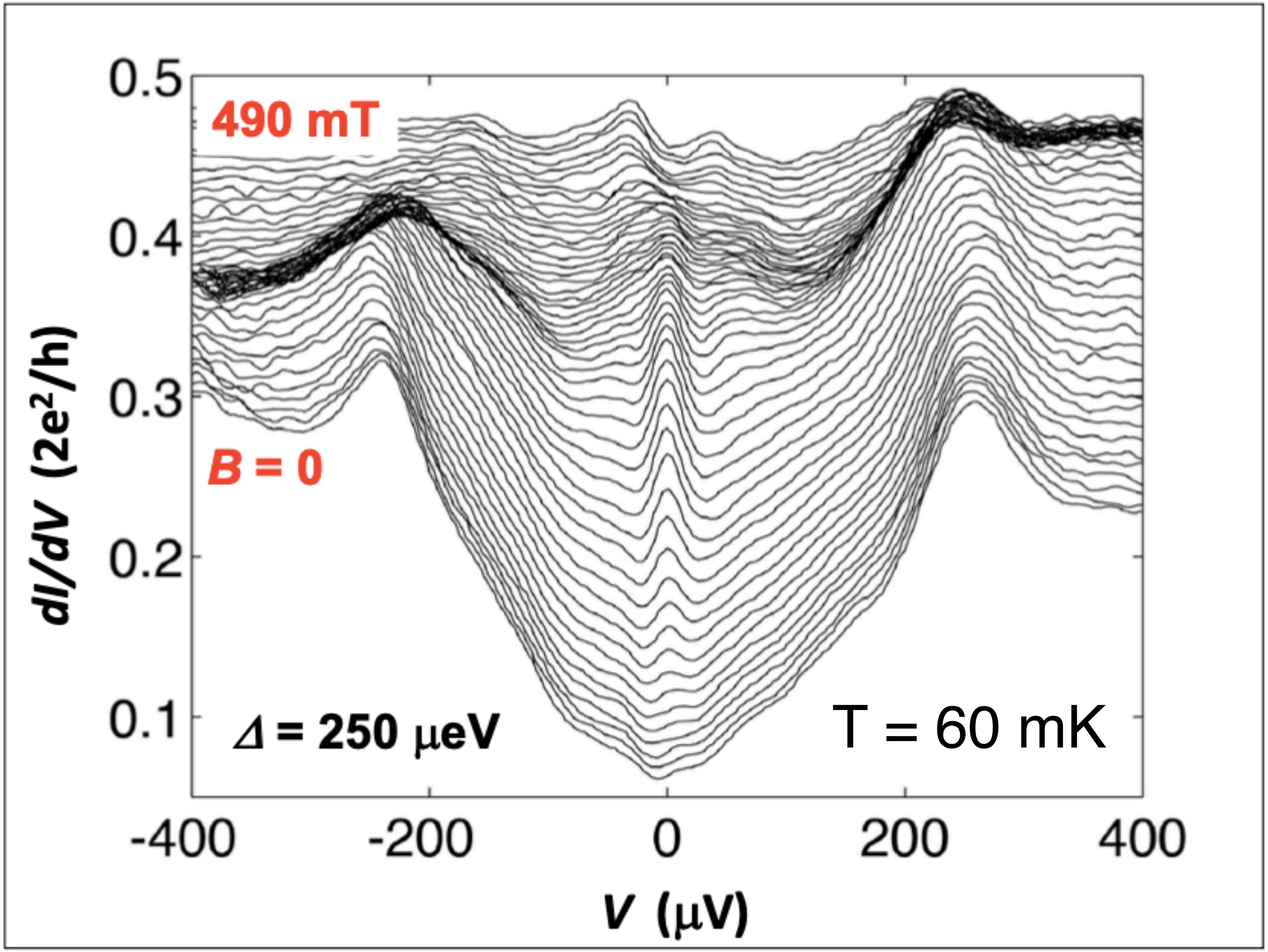


length ~ 3 µm, diameter 100 nm

Nanowires grown by S. Plissard and E. Bakkers
Plissard et al, Nano Letters 2012


Ti/Au
NbTiN
InSb
nanowire
500 nm

Observation of zero bias peak



V. Mourik et al. Science (2012)

Zero-Bias Peak ⟶ Majorana Bound State ??

Widespread in mesoscopic systems

Lots of possibilities for sub gap
states of non-topological origin
(disorder, imperfect superconductor…)

Necessary but insufficient condition….
quantization ??

(Finite T, finite wire length, tunneling into
non-Majorana states and disorder could be important)

TOPOLOGICAL SUPERCONDUCTIVITY

Quantized, finally

Quantized Majorana conductance is a hallmark of topological superconductors, but its fragility has made it difficult to observe. Device improvements have now enabled its measurement, making everyone eager to see the next step — topological qubits.

Marcel Franz and Dmitry I. Pikulin

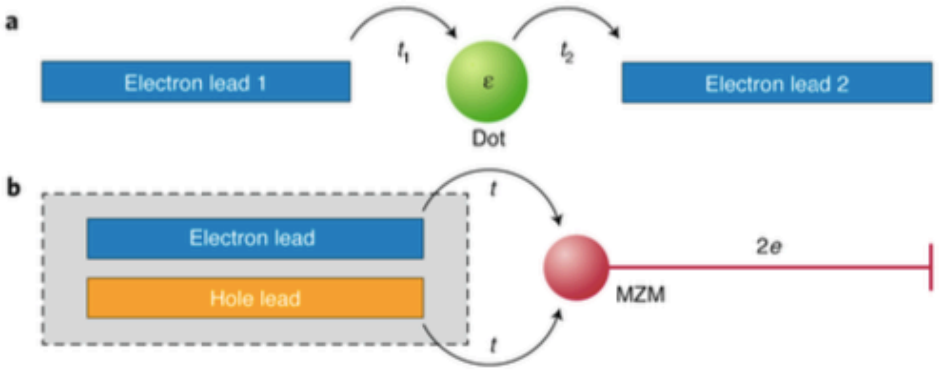
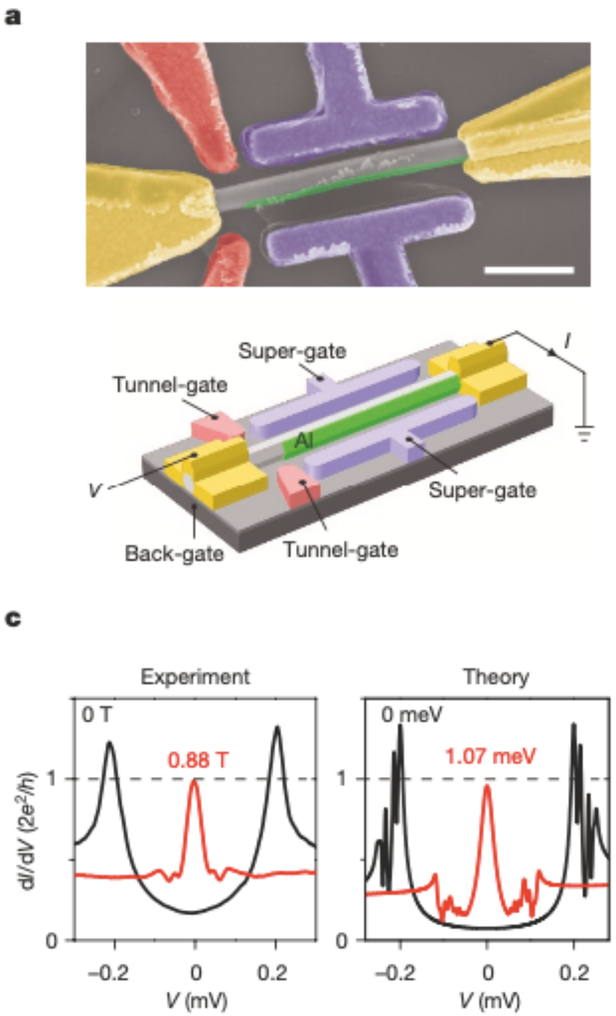


Fig. 1 | Resonant transmission and Andreev reflection. a, Two leads are attached to an island, which we model, for the sake of simplicity, as a single electron level with energy ε. An electron can hop on and off the island from the two leads and the respective tunnelling amplitudes are t_1 and t_2. **b**, A lead is attached to the Majorana-harbouring device, such as the Al-covered InSb wire employed in the experiment of Zhang and colleagues[4]. An electron or a hole from the lead can tunnel into the Majorana zero mode (MZM) with equal amplitude.

NATURE PHYSICS | VOL 14 | APRIL 2018 | 329–337 | www.nature.com/naturephysics

Quantized Majorana conductance



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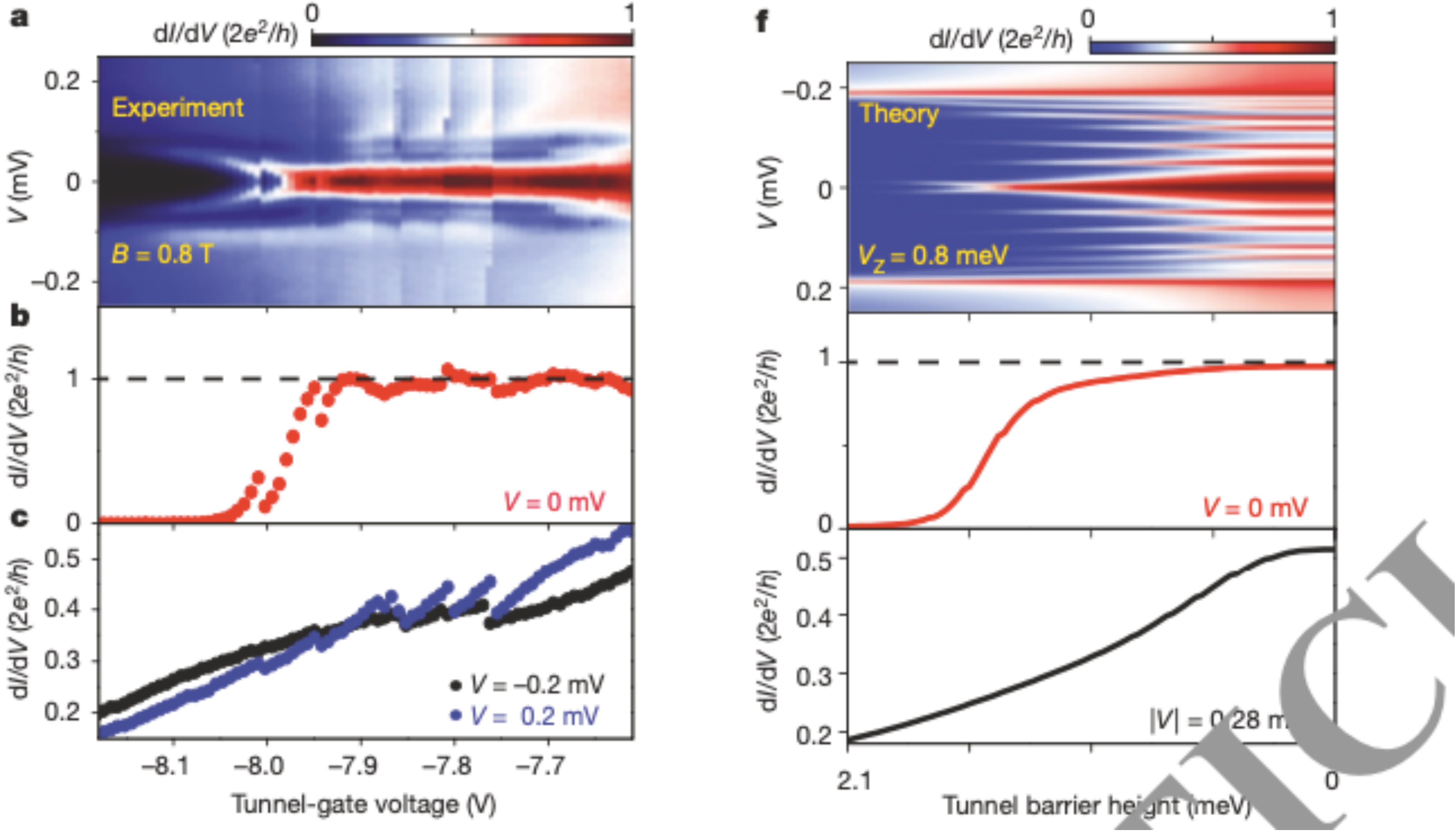
Quantized Majorana conductance



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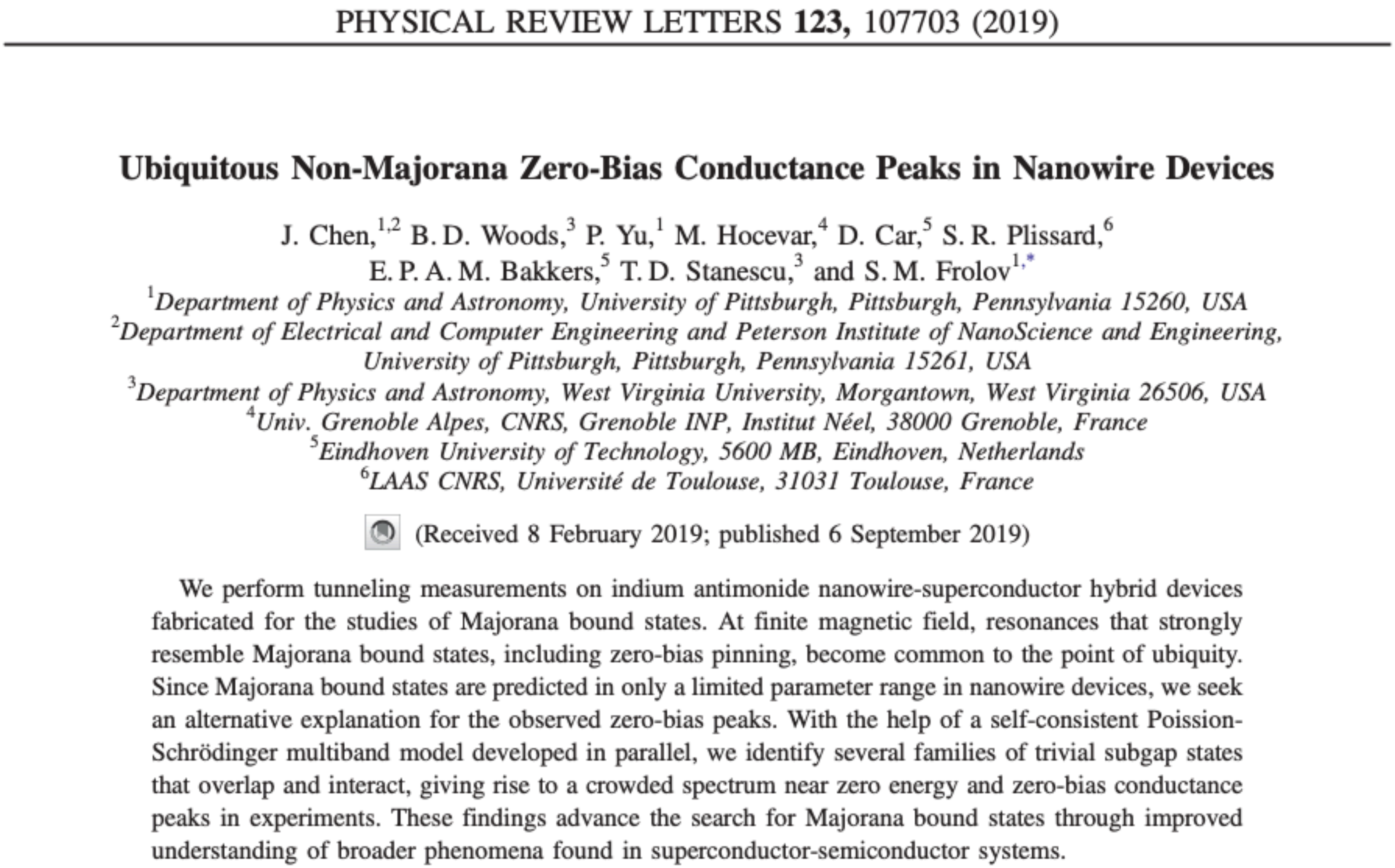
Questions ??

What about the other end of the wire ??

Parameter Regime ??

Is it possible to get this
result without topology ??

Correlation between gap in the nanowire
and the ZBPs at both ends ??



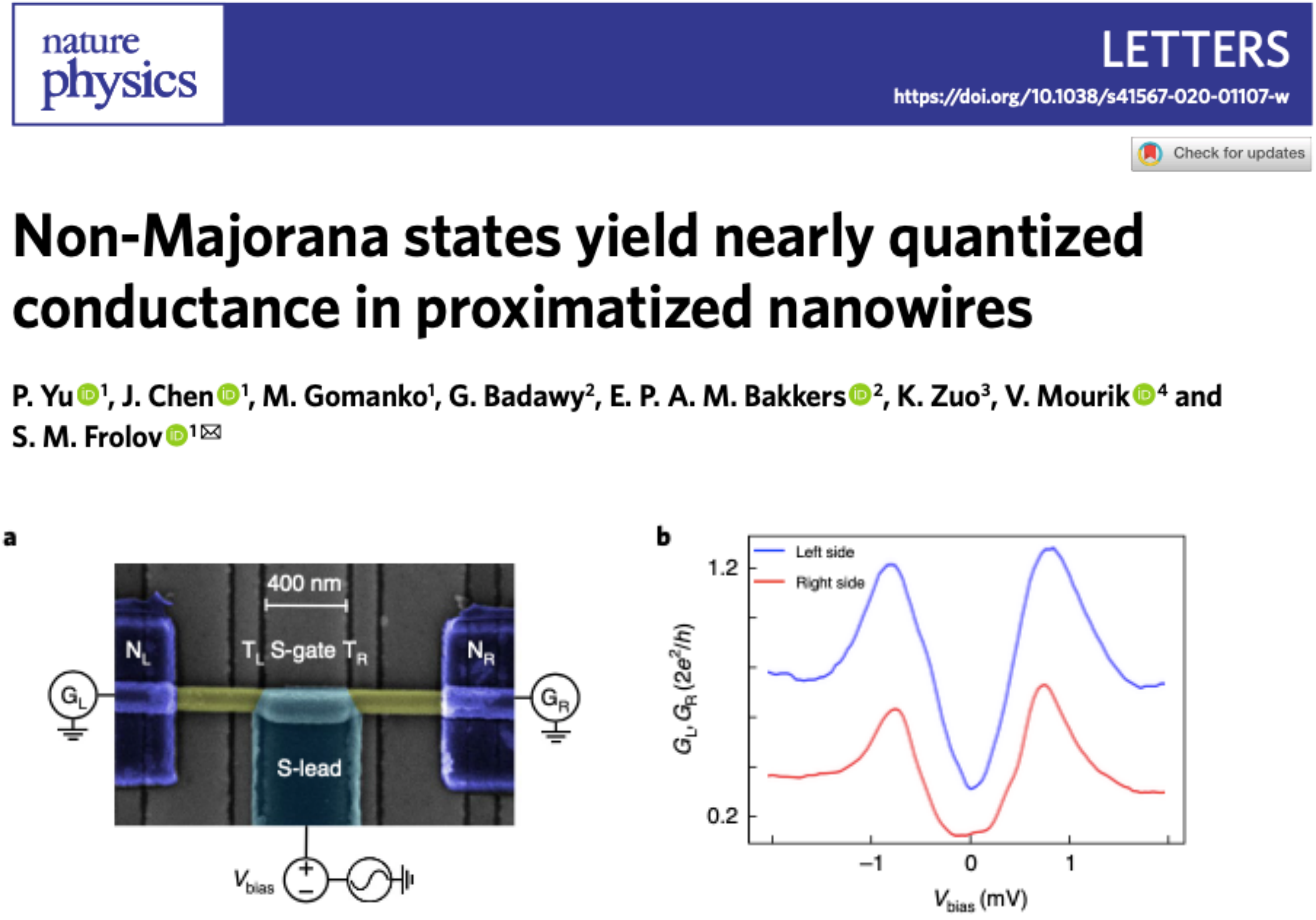
PHYSICAL REVIEW LETTERS **123,** 107703 (2019)

Ubiquitous Non-Majorana Zero-Bias Conductance Peaks in Nanowire Devices

J. Chen,[1,2] B. D. Woods,[3] P. Yu,[1] M. Hocevar,[4] D. Car,[5] S. R. Plissard,[6]
E. P. A. M. Bakkers,[5] T. D. Stanescu,[3] and S. M. Frolov[1,*]
[1]*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA*
[2]*Department of Electrical and Computer Engineering and Peterson Institute of NanoScience and Engineering, University of Pittsburgh, Pittsburgh, Pennsylvania 15261, USA*
[3]*Department of Physics and Astronomy, West Virginia University, Morgantown, West Virginia 26506, USA*
[4]*Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France*
[5]*Eindhoven University of Technology, 5600 MB, Eindhoven, Netherlands*
[6]*LAAS CNRS, Université de Toulouse, 31031 Toulouse, France*

(Received 8 February 2019; published 6 September 2019)

We perform tunneling measurements on indium antimonide nanowire-superconductor hybrid devices fabricated for the studies of Majorana bound states. At finite magnetic field, resonances that strongly resemble Majorana bound states, including zero-bias pinning, become common to the point of ubiquity. Since Majorana bound states are predicted in only a limited parameter range in nanowire devices, we seek an alternative explanation for the observed zero-bias peaks. With the help of a self-consistent Poission-Schrödinger multiband model developed in parallel, we identify several families of trivial subgap states that overlap and interact, giving rise to a crowded spectrum near zero energy and zero-bias conductance peaks in experiments. These findings advance the search for Majorana bound states through improved understanding of broader phenomena found in superconductor-semiconductor systems.



nature physics

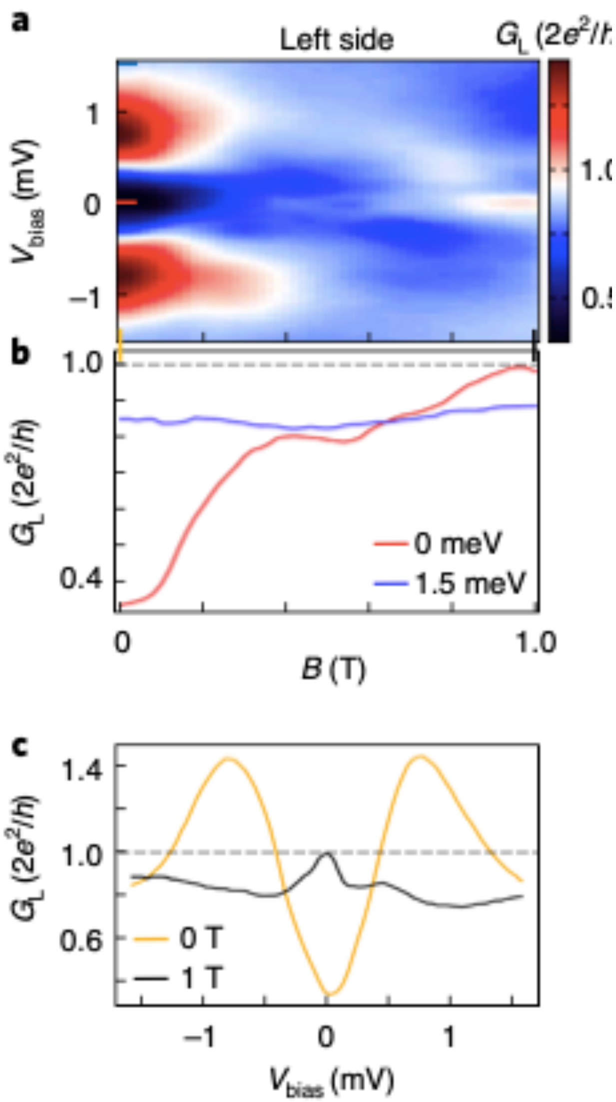
LETTERS

https://doi.org/10.1038/s41567-020-01107-w

Check for updates

Non-Majorana states yield nearly quantized conductance in proximatized nanowires

P. Yu[1], J. Chen[1], M. Gomanko[1], G. Badawy[2], E. P. A. M. Bakkers[2], K. Zuo[3], V. Mourik[4] and S. M. Frolov[1]✉



Zero-Bias Peaks Evolve with Tunnel Barrier Strength and Magnetic Field in Manner Consistent with Expectation for Majorana Modes

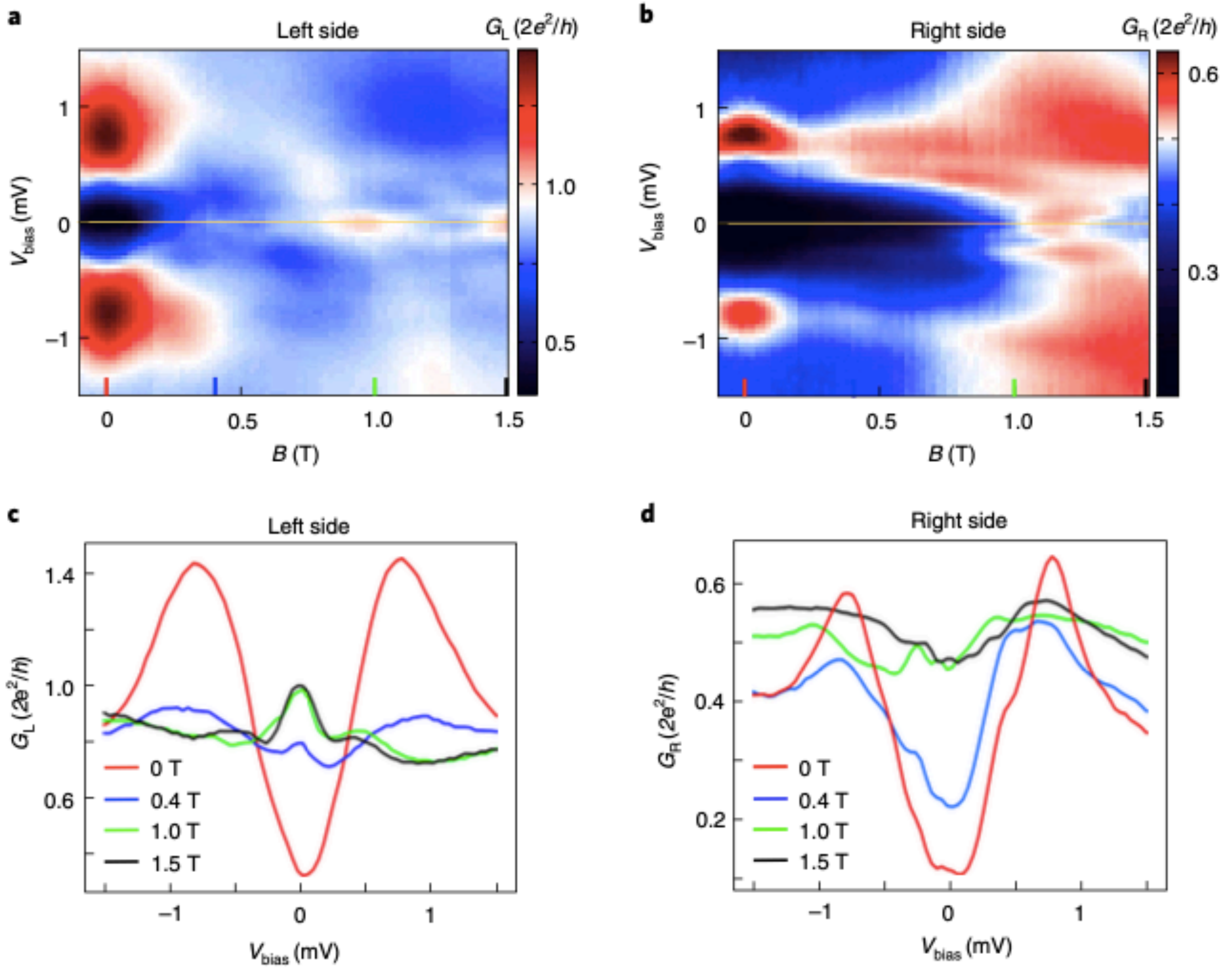
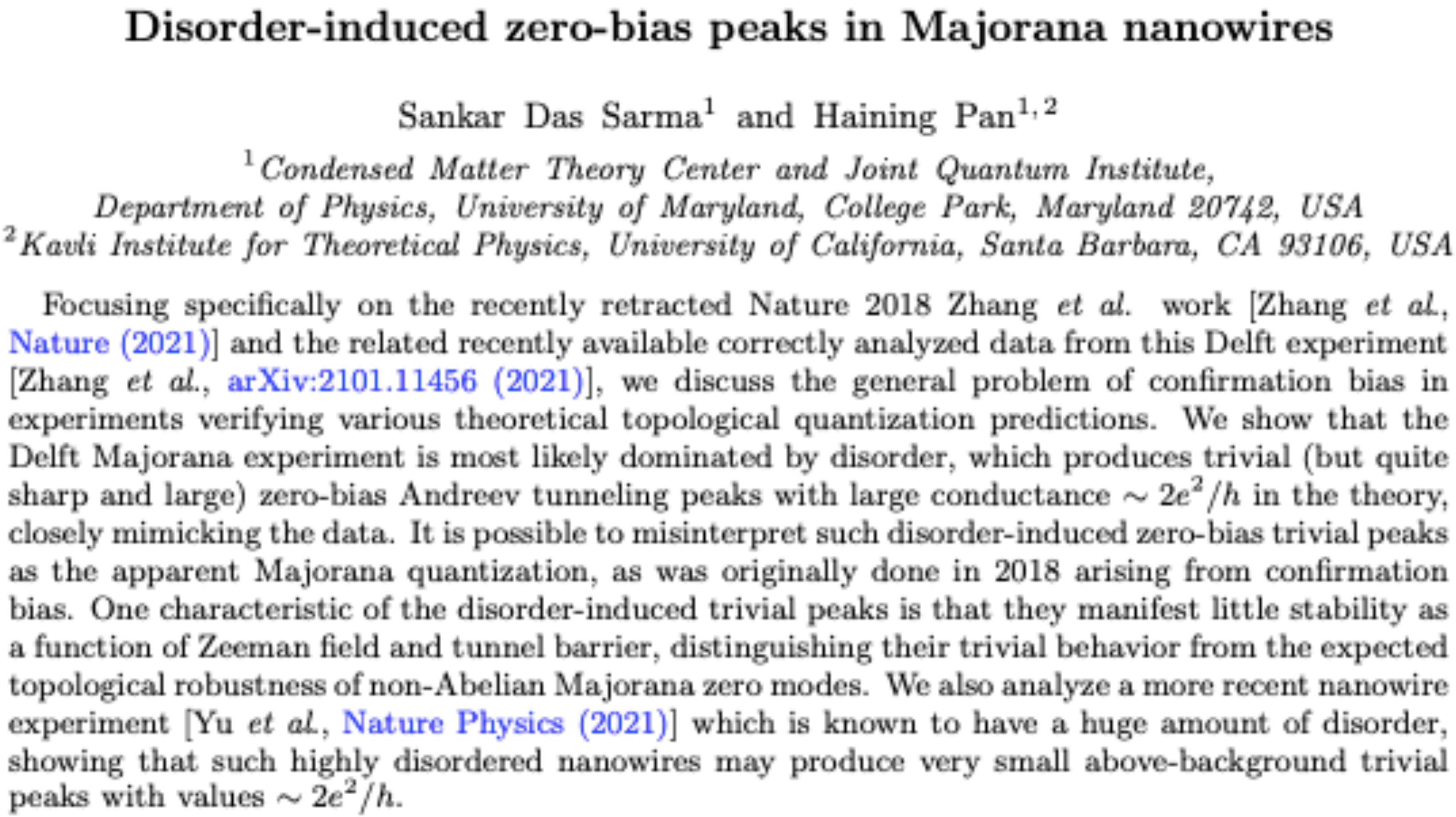


Fig. 3 | Absence of zero-bias peak on the right side. a,**b**, Magnetic field dependence of the subgap states on the left (**a**) and right (**b**) sides from the same dataset as in Fig. 2a, now in an expanded field range, with an S-gate voltage of −0.17 V, $T_L = -0.045$ V and $T_R = -0.105$ V. A contact resistance of 4 kΩ is subtracted for the left side. **c**,**d**, Bias linecuts at 0 T, 0.4 T, 1.0 T and 1.5 T taken from **a** (**c**) and **b** (**d**).



Disorder-induced zero-bias peaks in Majorana nanowires

Sankar Das Sarma[1] and Haining Pan[1,2]

[1] *Condensed Matter Theory Center and Joint Quantum Institute,*
Department of Physics, University of Maryland, College Park, Maryland 20742, USA
[2] *Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA*

Focusing specifically on the recently retracted Nature 2018 Zhang *et al.* work [Zhang *et al.*, Nature (2021)] and the related recently available correctly analyzed data from this Delft experiment [Zhang *et al.*, arXiv:2101.11456 (2021)], we discuss the general problem of confirmation bias in experiments verifying various theoretical topological quantization predictions. We show that the Delft Majorana experiment is most likely dominated by disorder, which produces trivial (but quite sharp and large) zero-bias Andreev tunneling peaks with large conductance $\sim 2e^2/h$ in the theory, closely mimicking the data. It is possible to misinterpret such disorder-induced zero-bias trivial peaks as the apparent Majorana quantization, as was originally done in 2018 arising from confirmation bias. One characteristic of the disorder-induced trivial peaks is that they manifest little stability as a function of Zeeman field and tunnel barrier, distinguishing their trivial behavior from the expected topological robustness of non-Abelian Majorana zero modes. We also analyze a more recent nanowire experiment [Yu *et al.*, Nature Physics (2021)] which is known to have a huge amount of disorder, showing that such highly disordered nanowires may produce very small above-background trivial peaks with values $\sim 2e^2/h$.

(March 9, 2021 on arXiv)

What's Next ??

Avoid confirmation bias !!

Local spectroscopic measurements insufficient

Non-local conductance measurements crucial

Still need better ways of distinguishing topological and non-topological zero-bias modes

Lots to do……