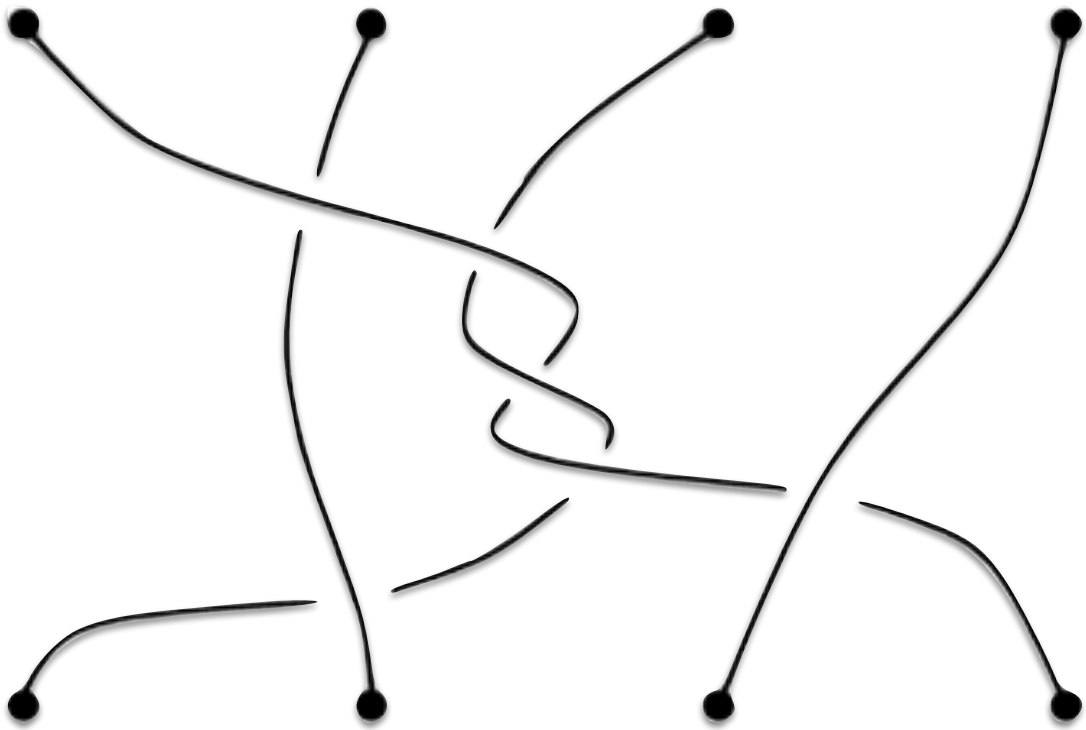
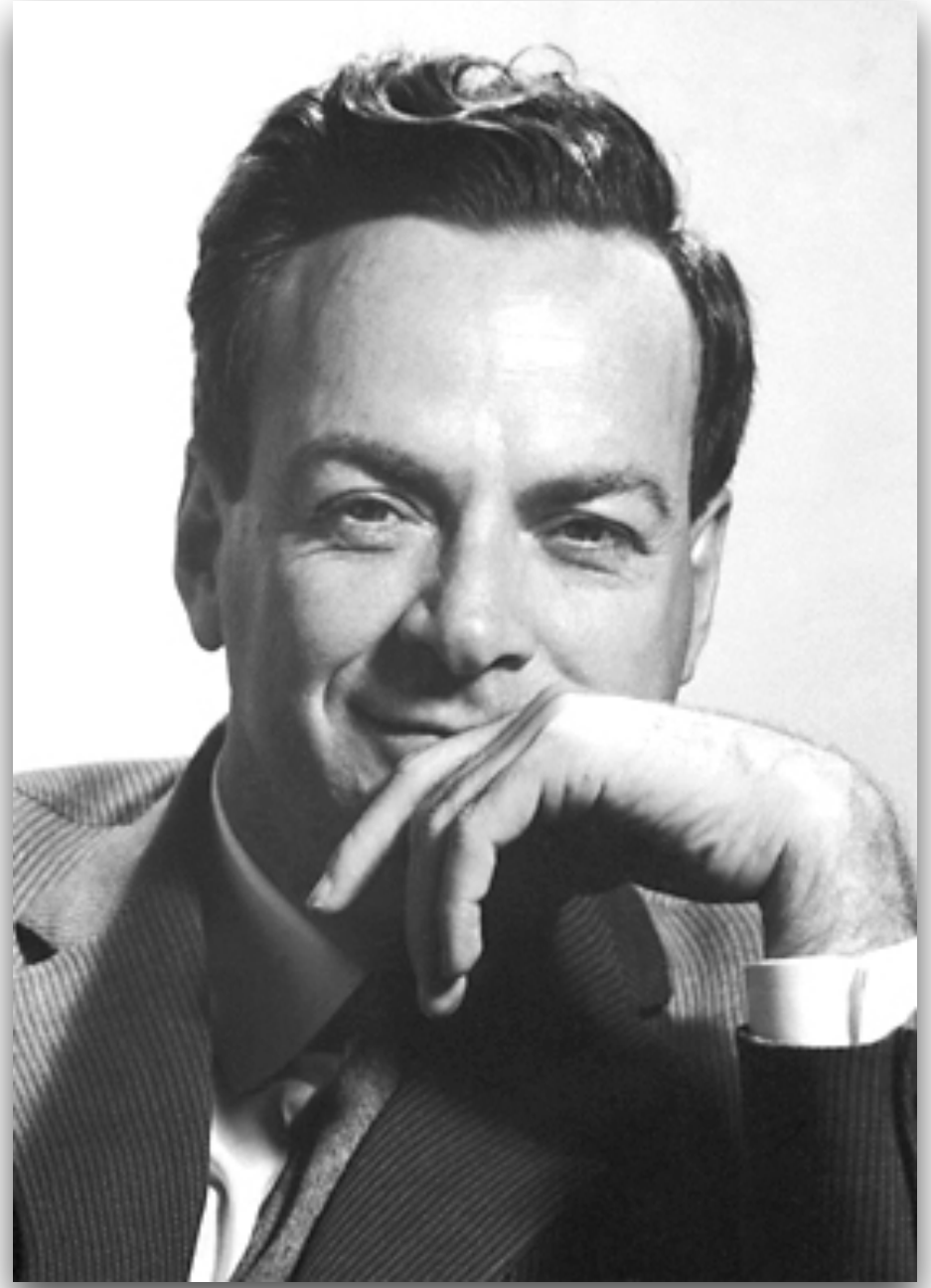
Topological Quantum Computing: Progress & Opportunities



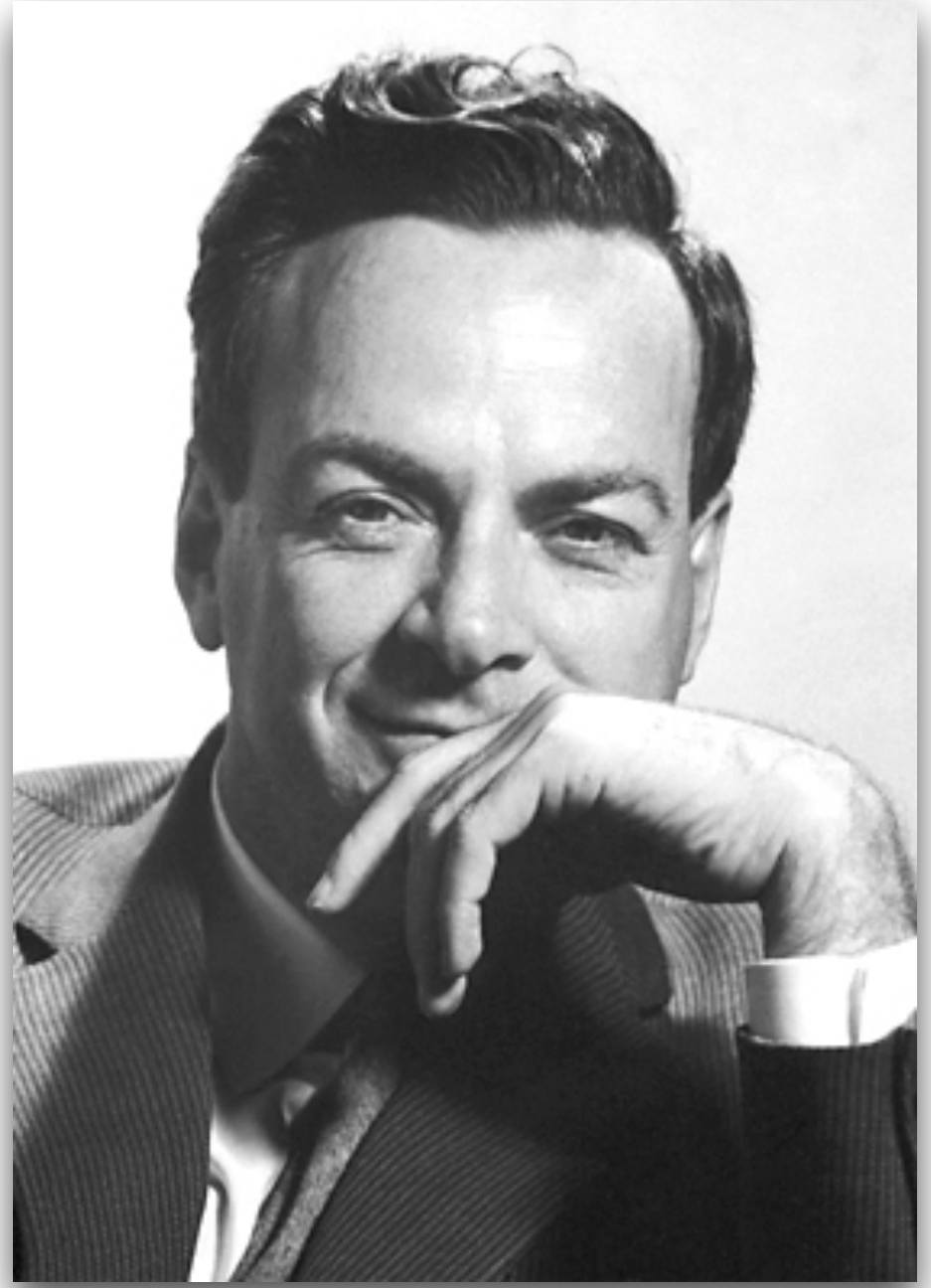
Jason Alicea

INSTITUTE FOR QUANTUM INFORMATION AND MATTER

BURKE INSTITUTE



Feynman 1982: quantum computing visionary



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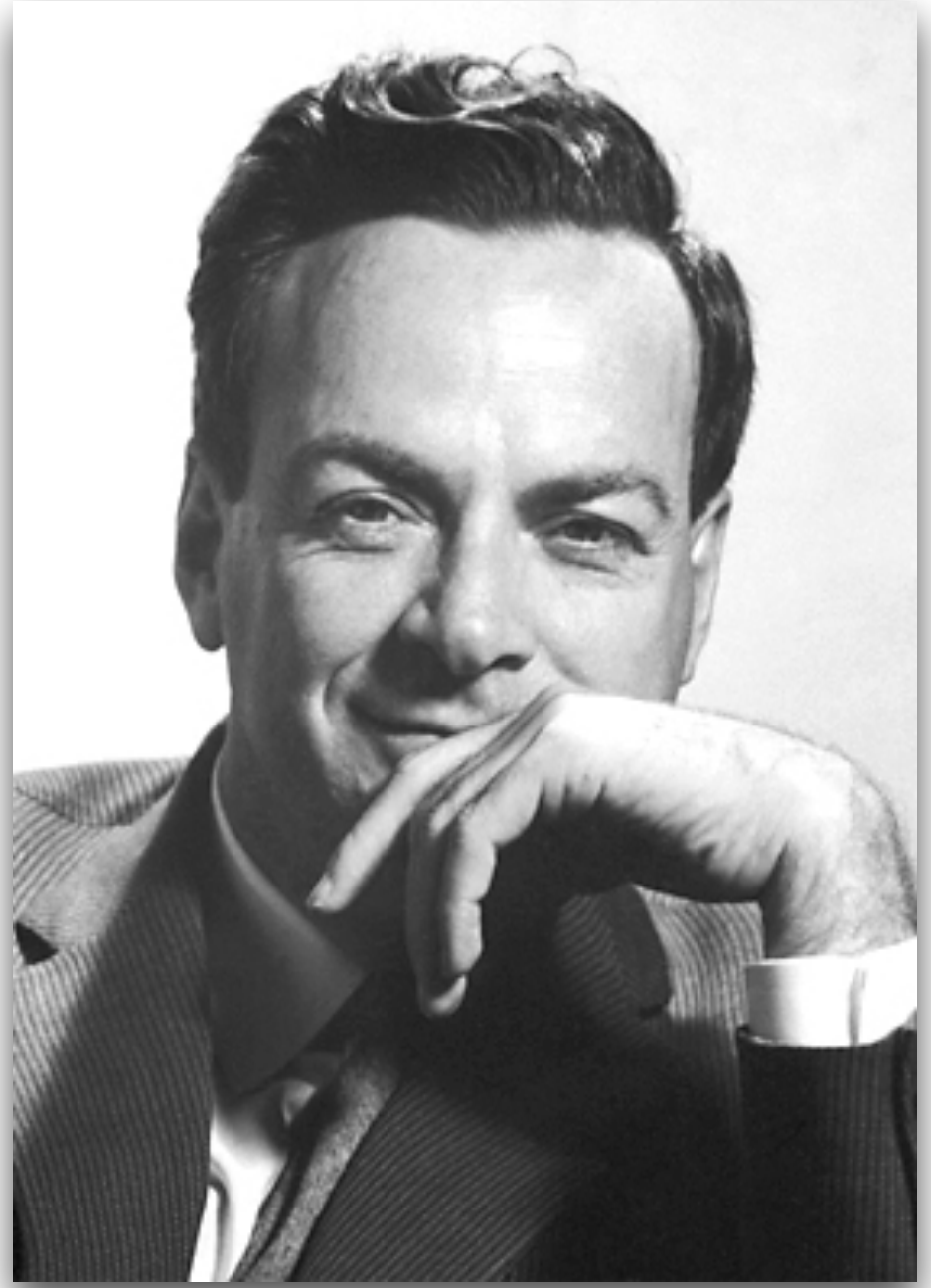
~$300



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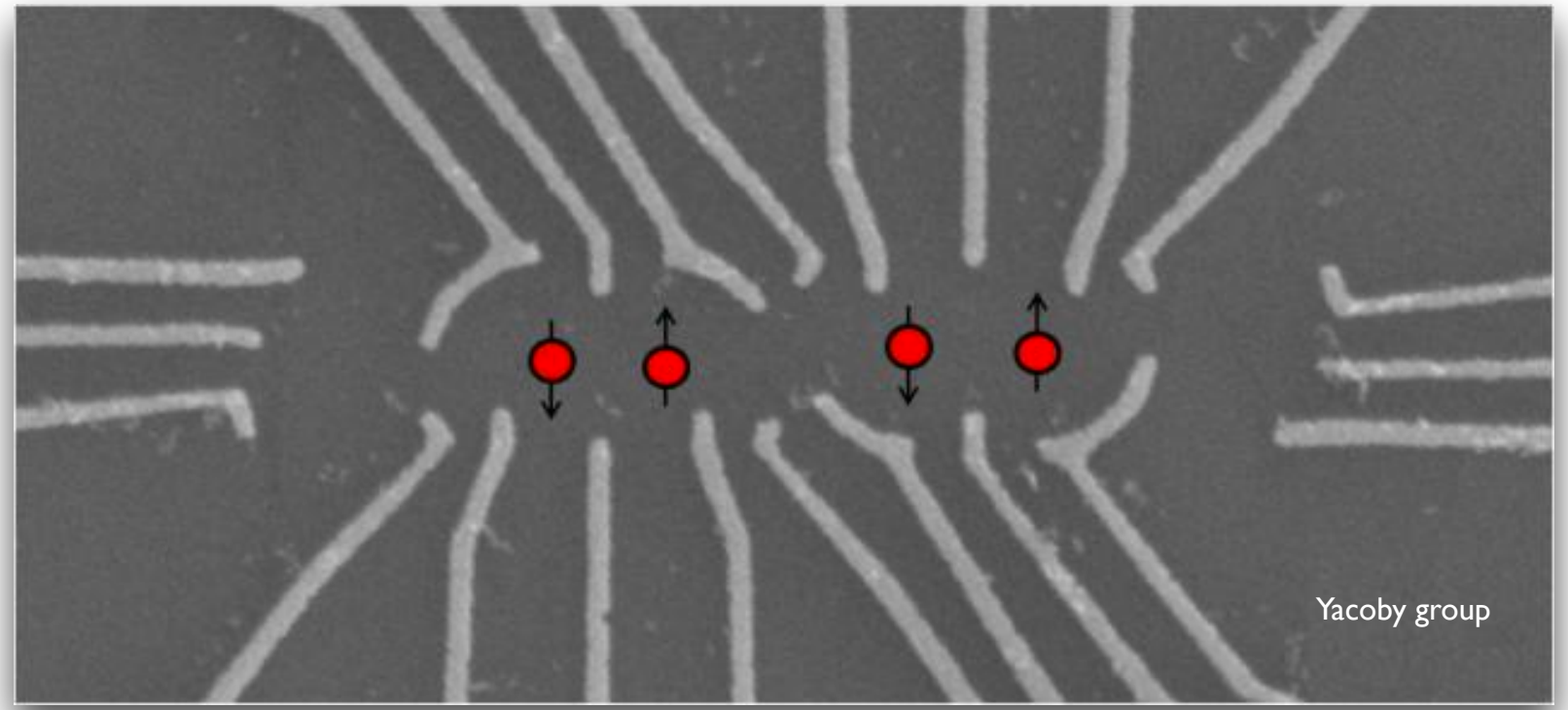
N/A

Quantum information tends to be fragile



$$|00\rangle + |11\rangle$$

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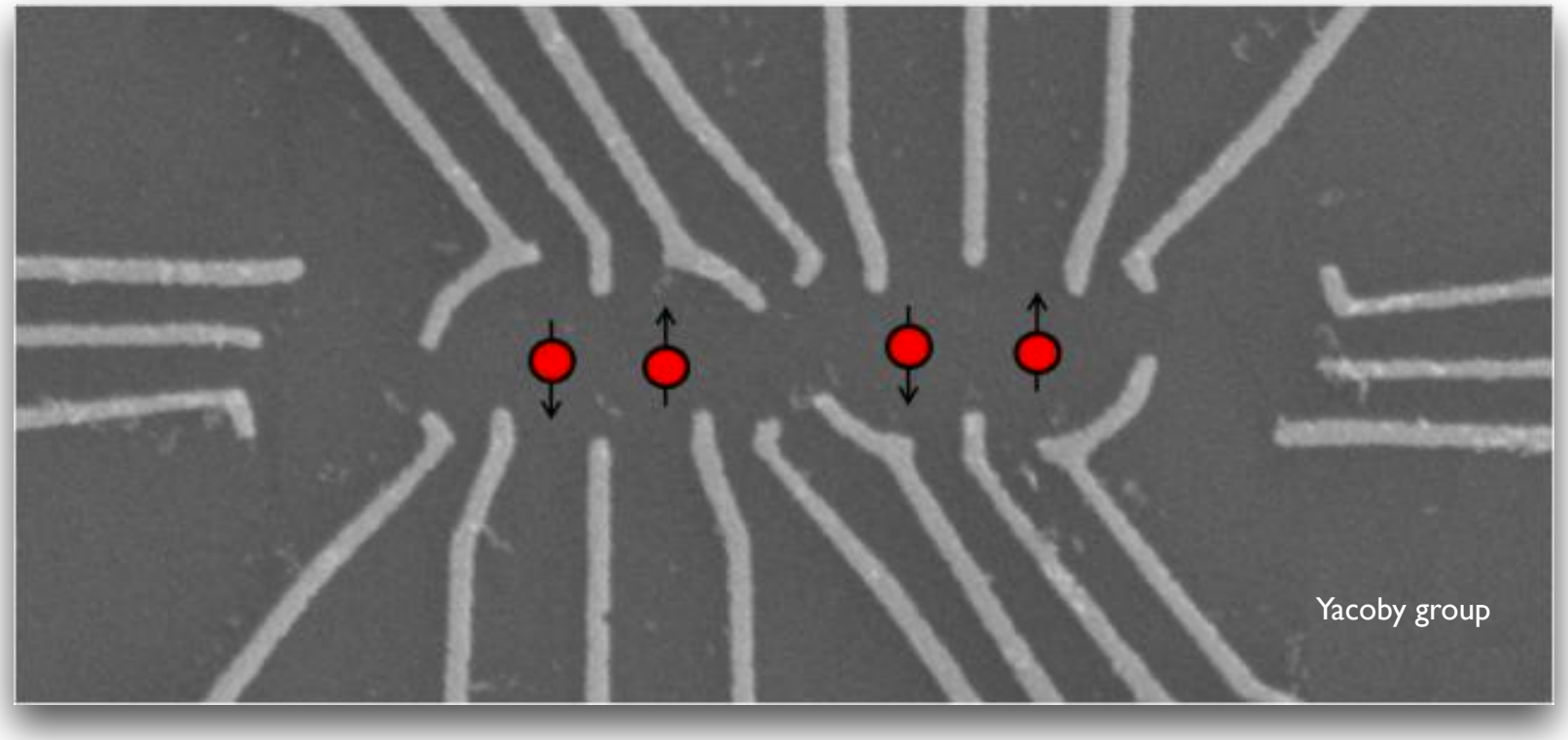

$$|00\rangle + |11\rangle \Rightarrow |00\rangle + e^{i\alpha}|11\rangle$$

random phase

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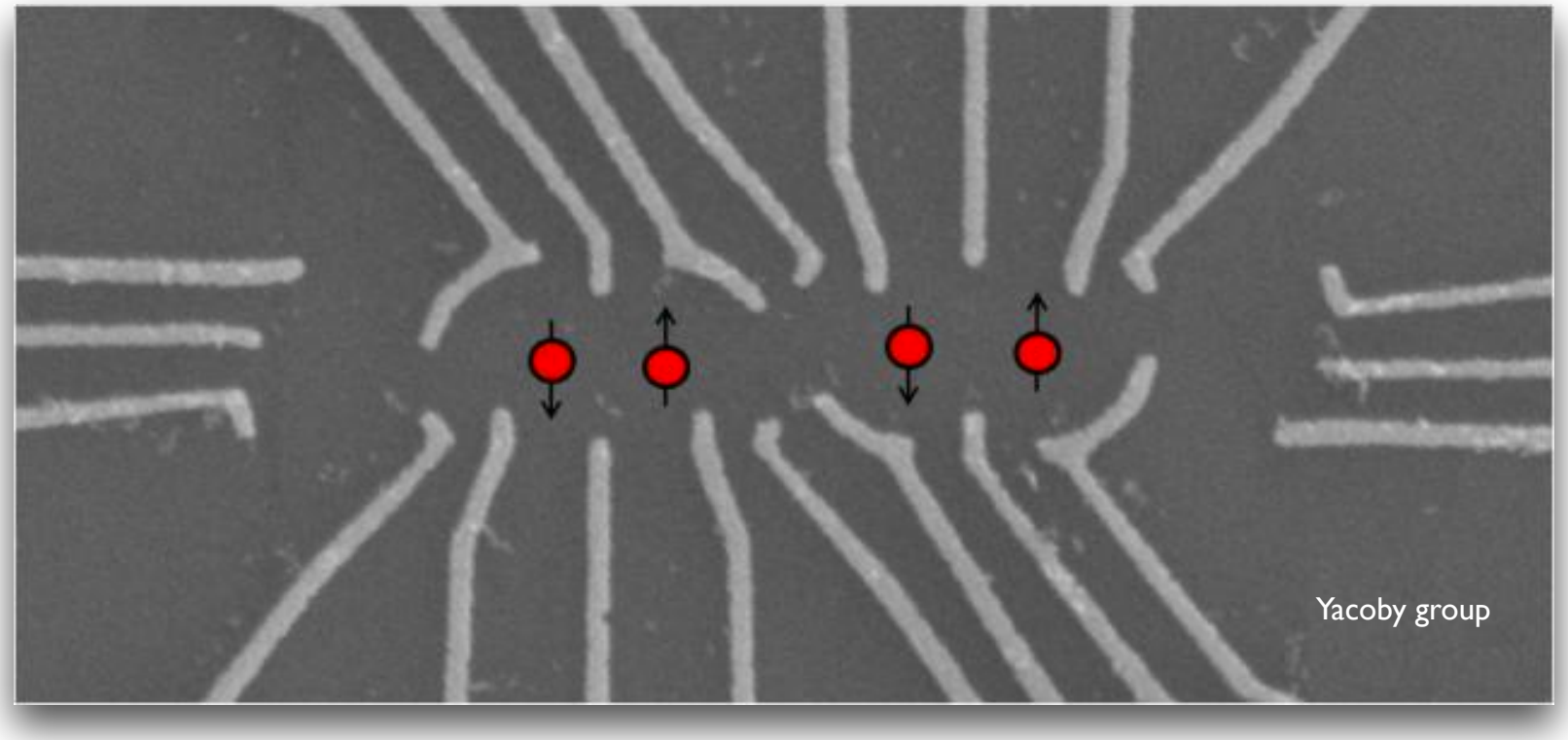

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A (three) million dollar idea

Kitaev 1997: **topological** quantum computing pioneer

Encode & process qubits w/ **(non-Abelian) anyons**— hardware immune to environmental noise!

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2012 Fundamental physics prize recipient!

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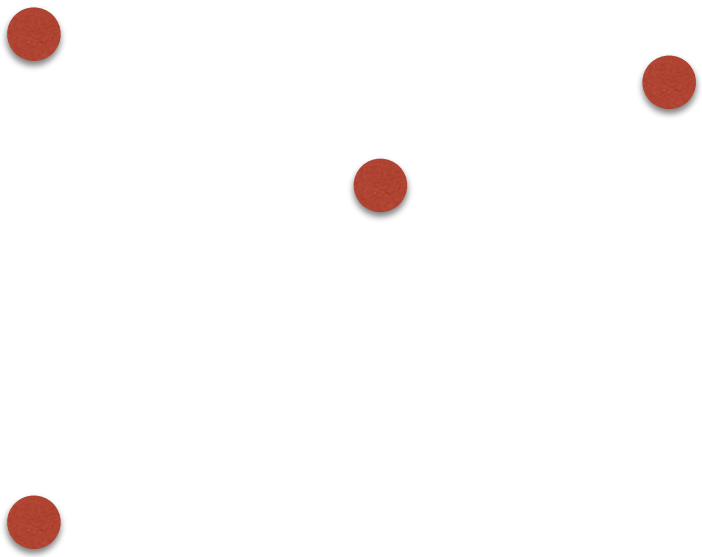

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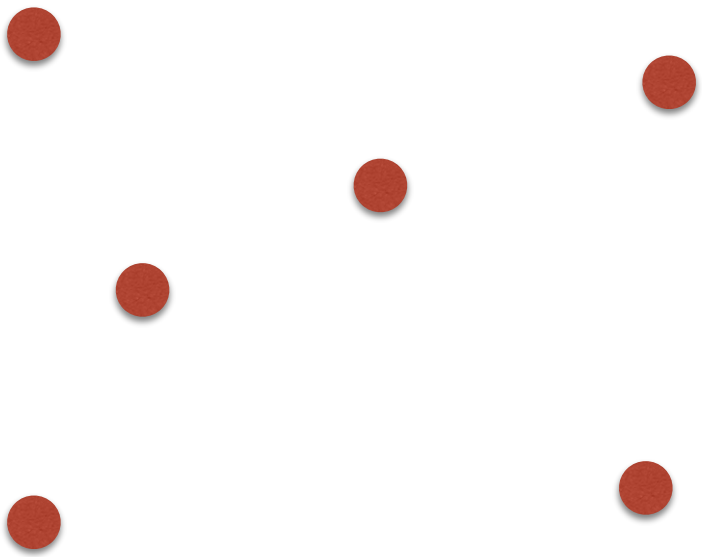

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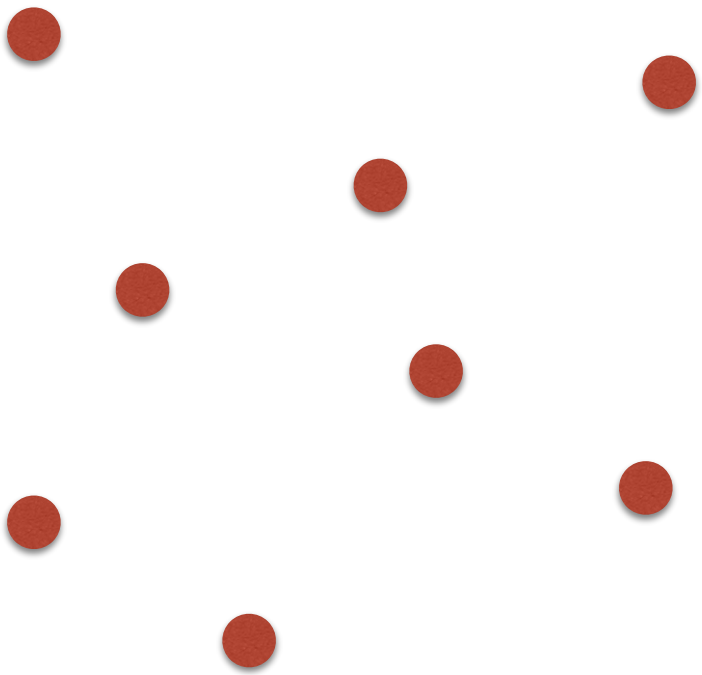
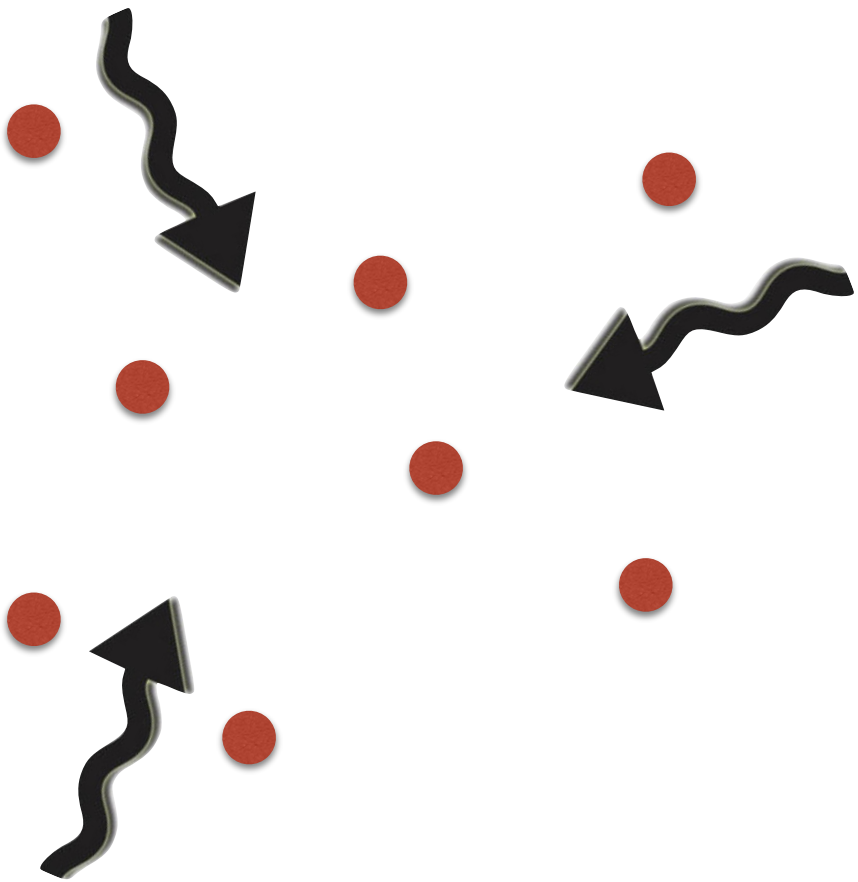


1. Exponentially many quantum states w/ same energy

$$\sim 2^{\frac{\#\ \text{anyons}}{2}}$$

Anyons



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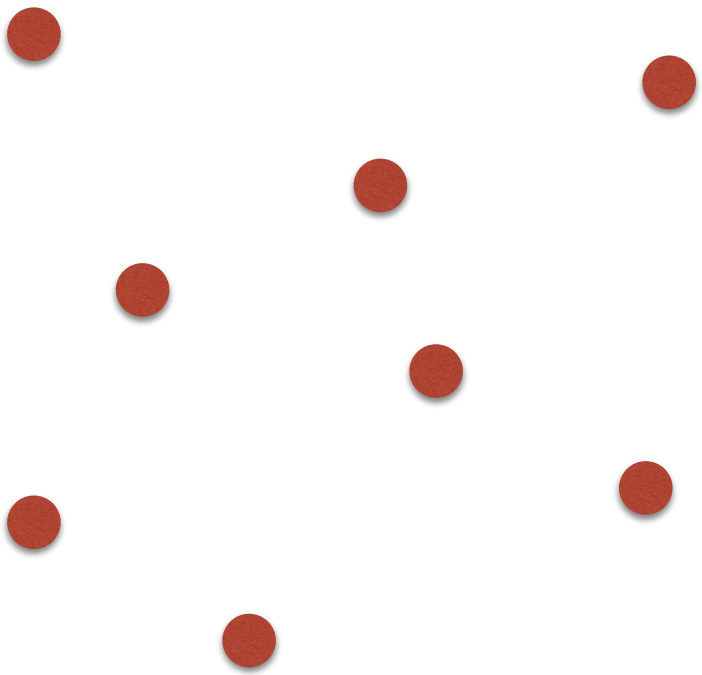

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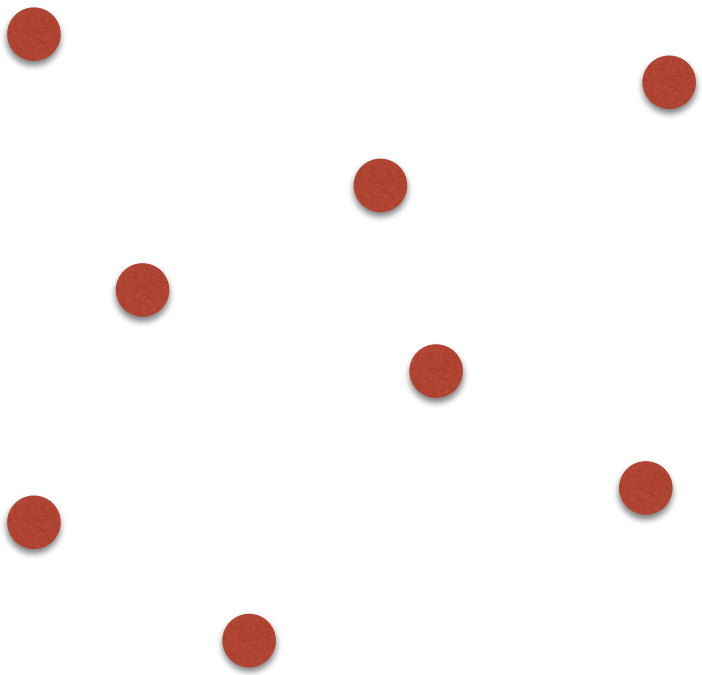

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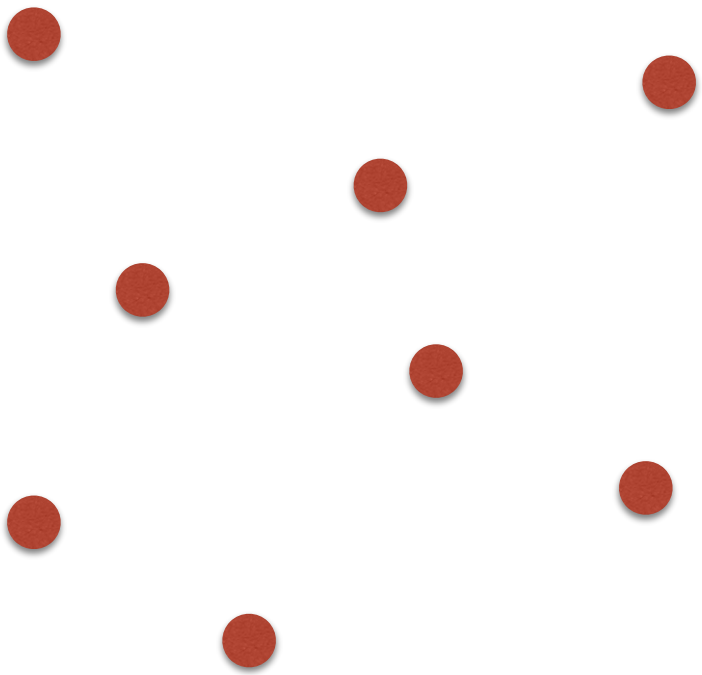

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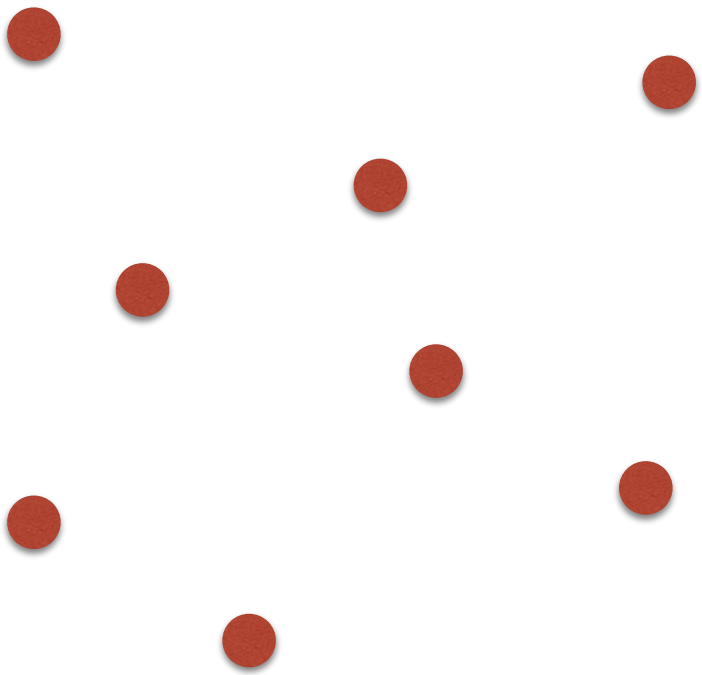

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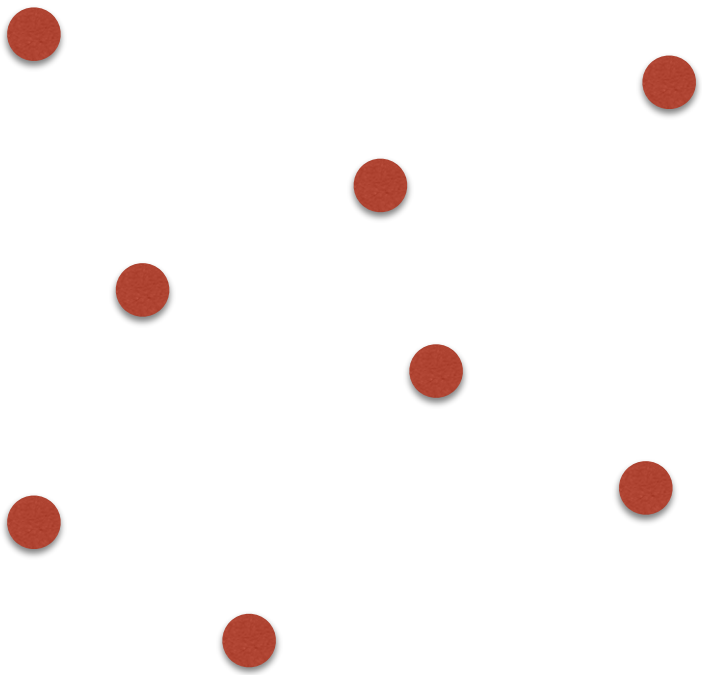

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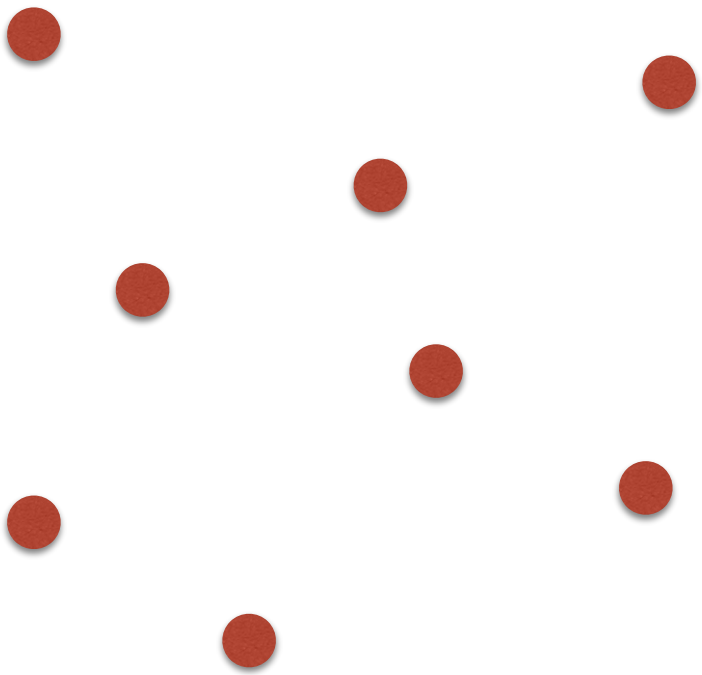

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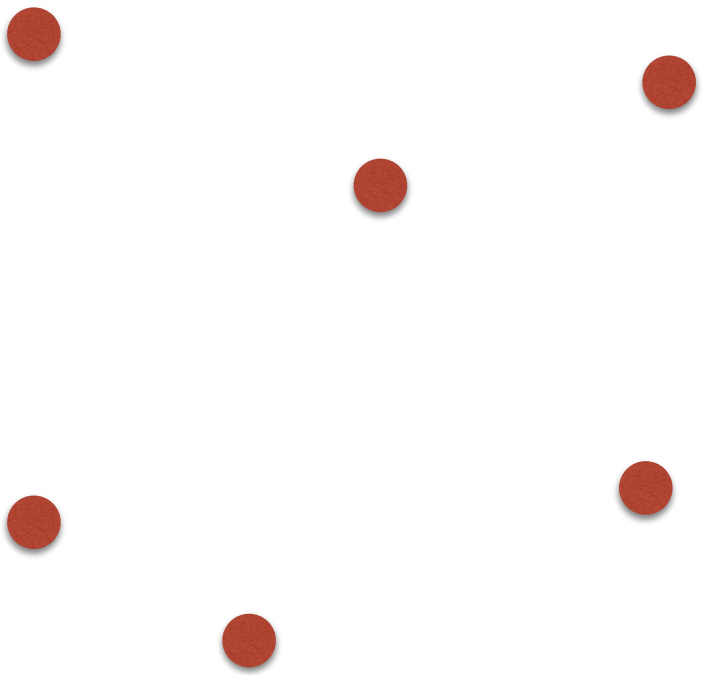

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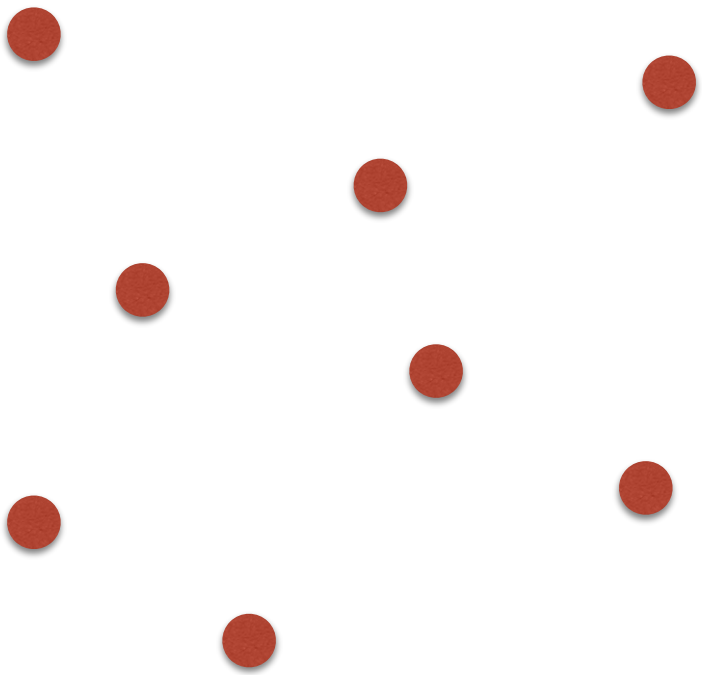

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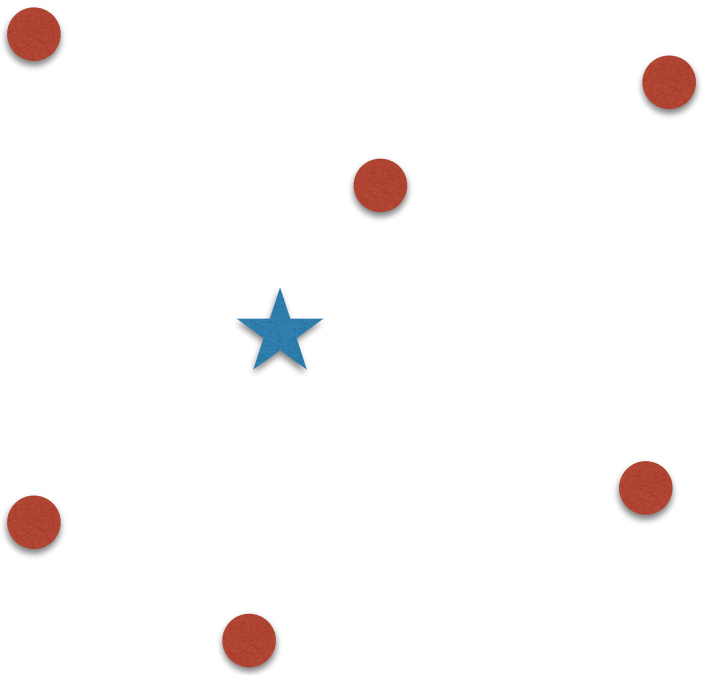

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Readout

Billion $ question:

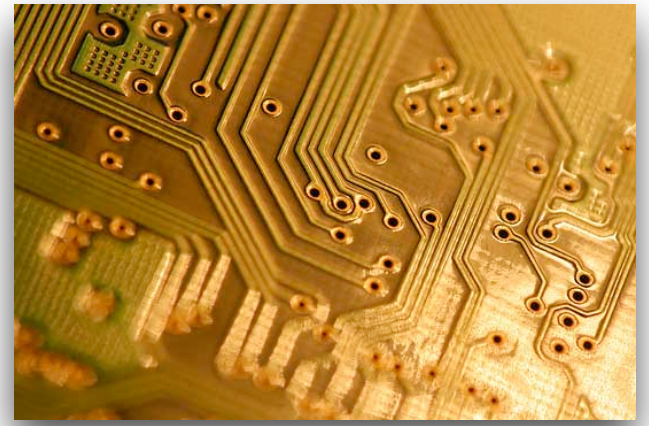
How do you build the hardware?

~~Serendipity~~

~~Serendipity~~

Engineering

~~Serendipity~~ **Engineering**



semiconducting wire +

Lutchyn, Sau, Das Sarma; Oreg, Refael, von Oppen (2010)

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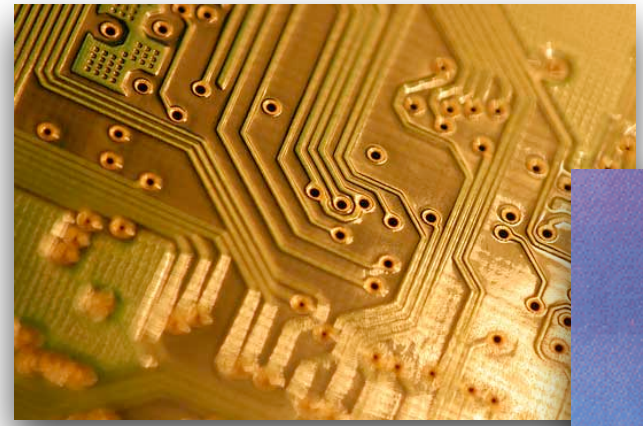

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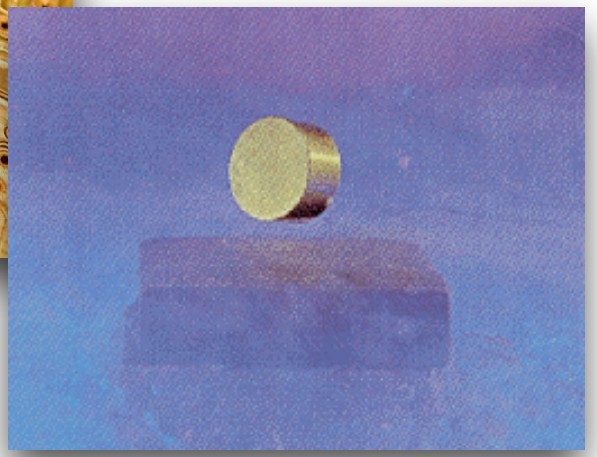

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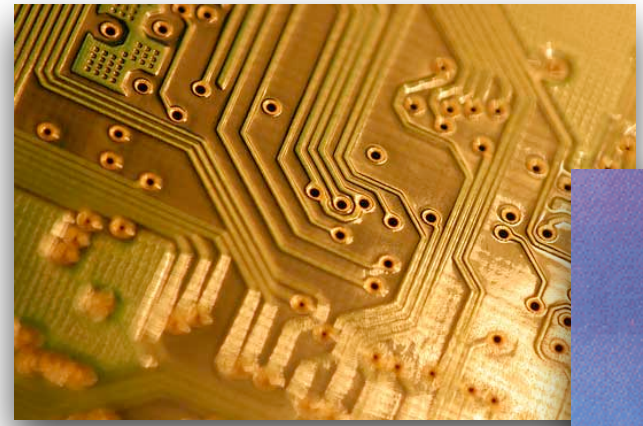

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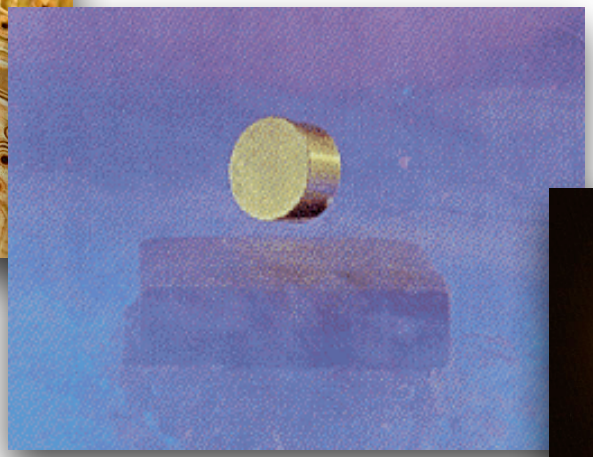

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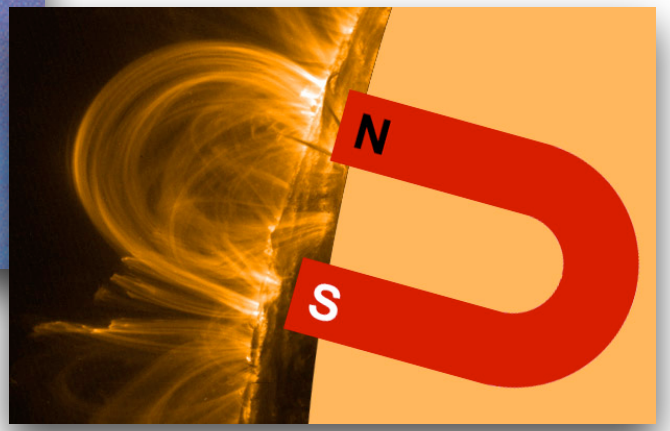

magnetic field

Lutchyn, Sau, Das Sarma; Oreg, Refael, von Oppen (2010)

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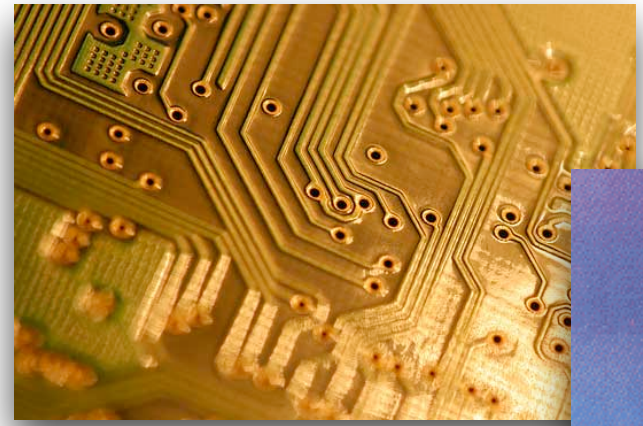

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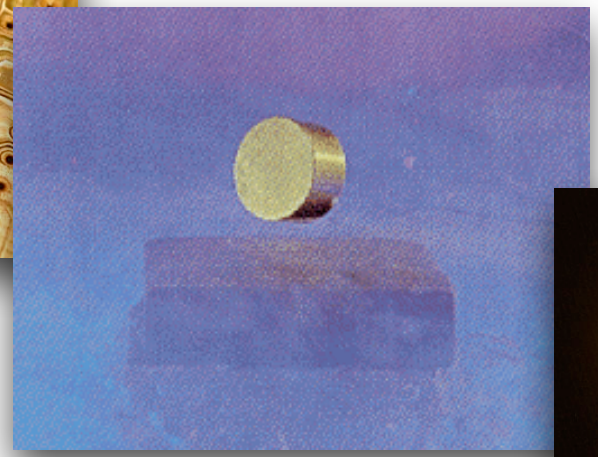

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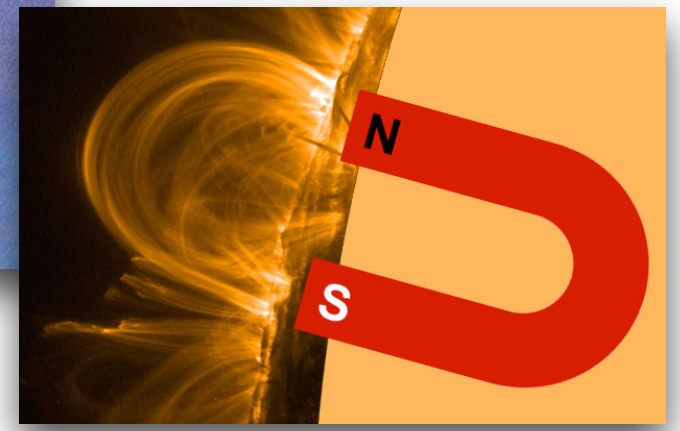

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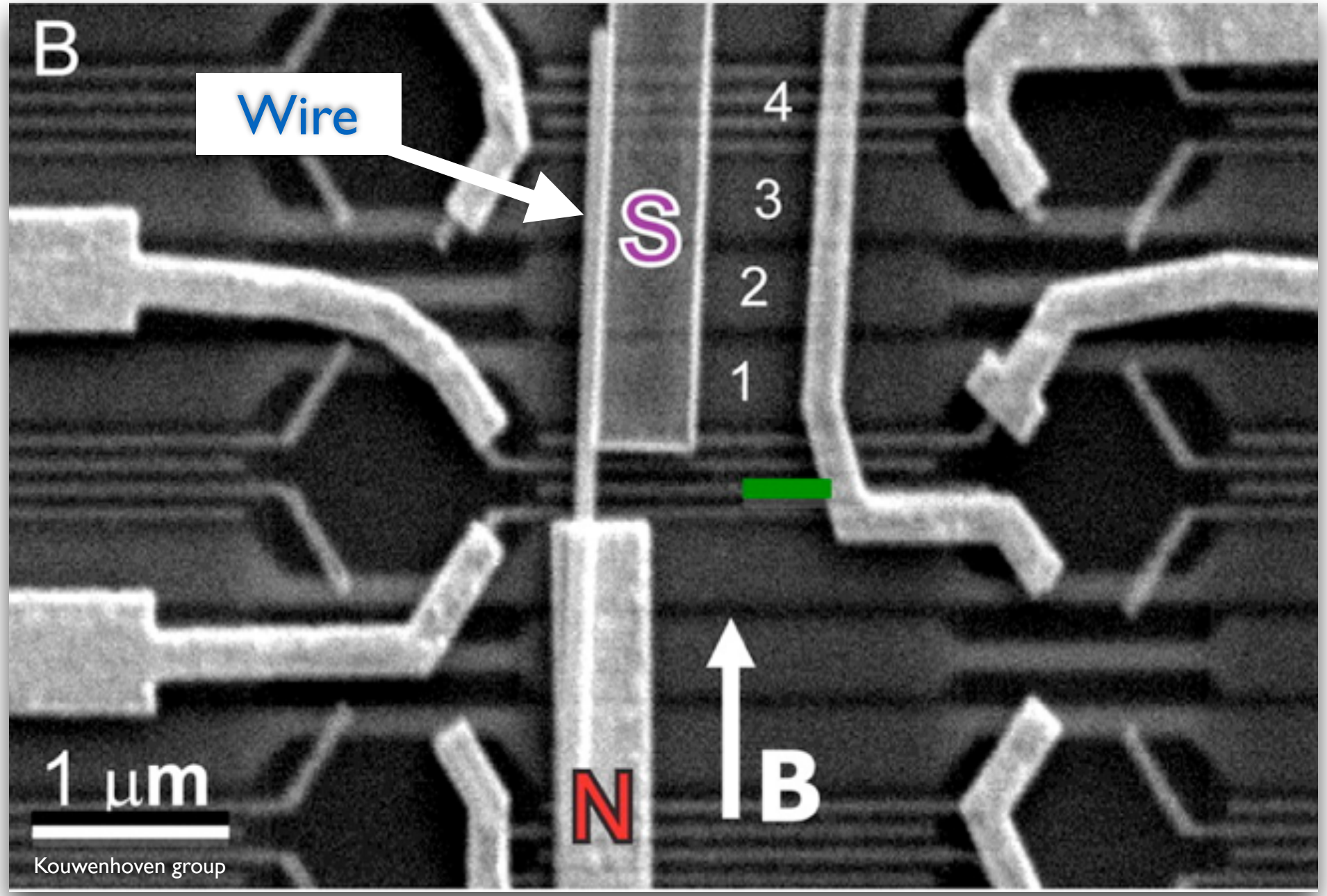
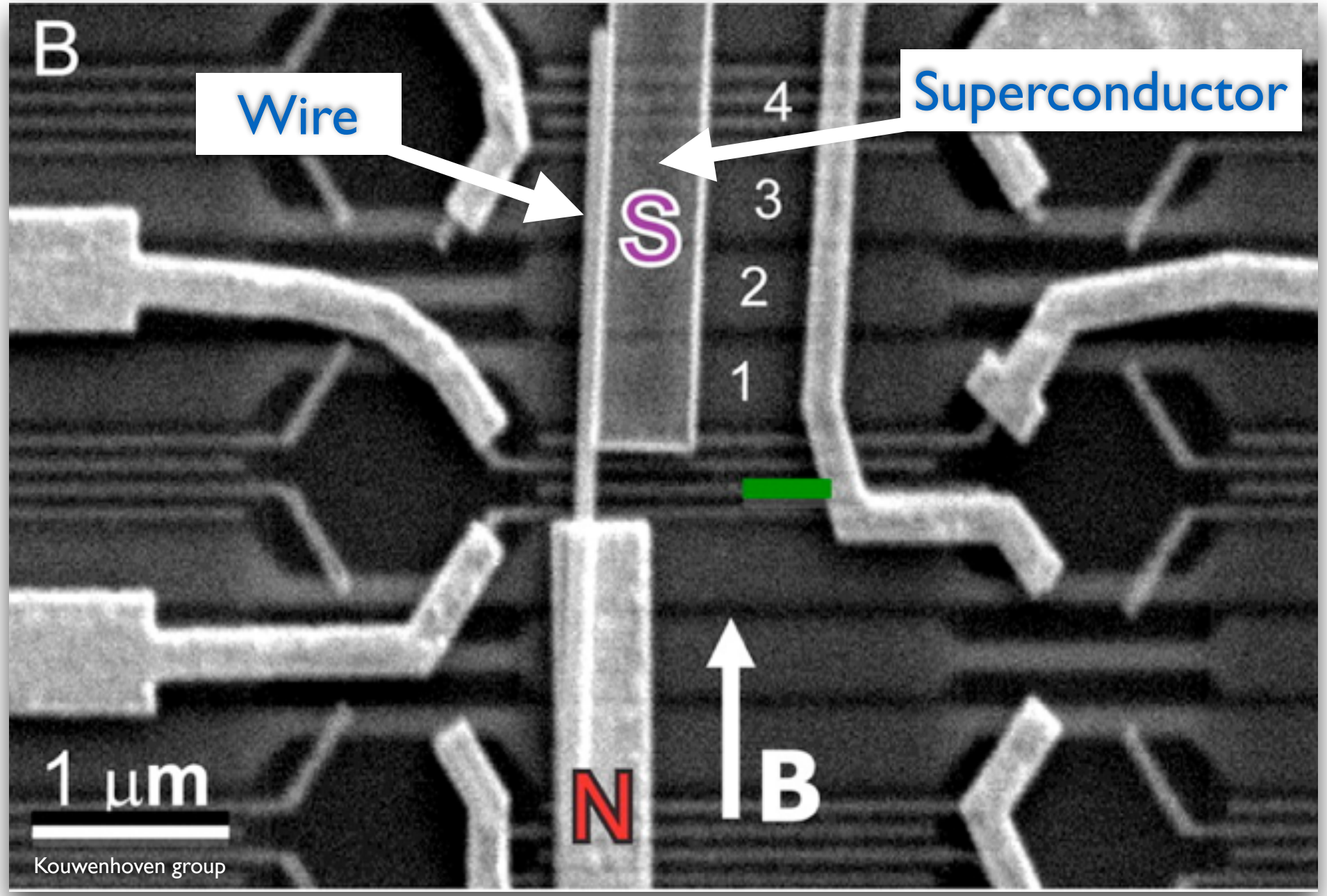

B
Wire
S
4
3
2
1
N
B
1 μm
Kouwenhoven group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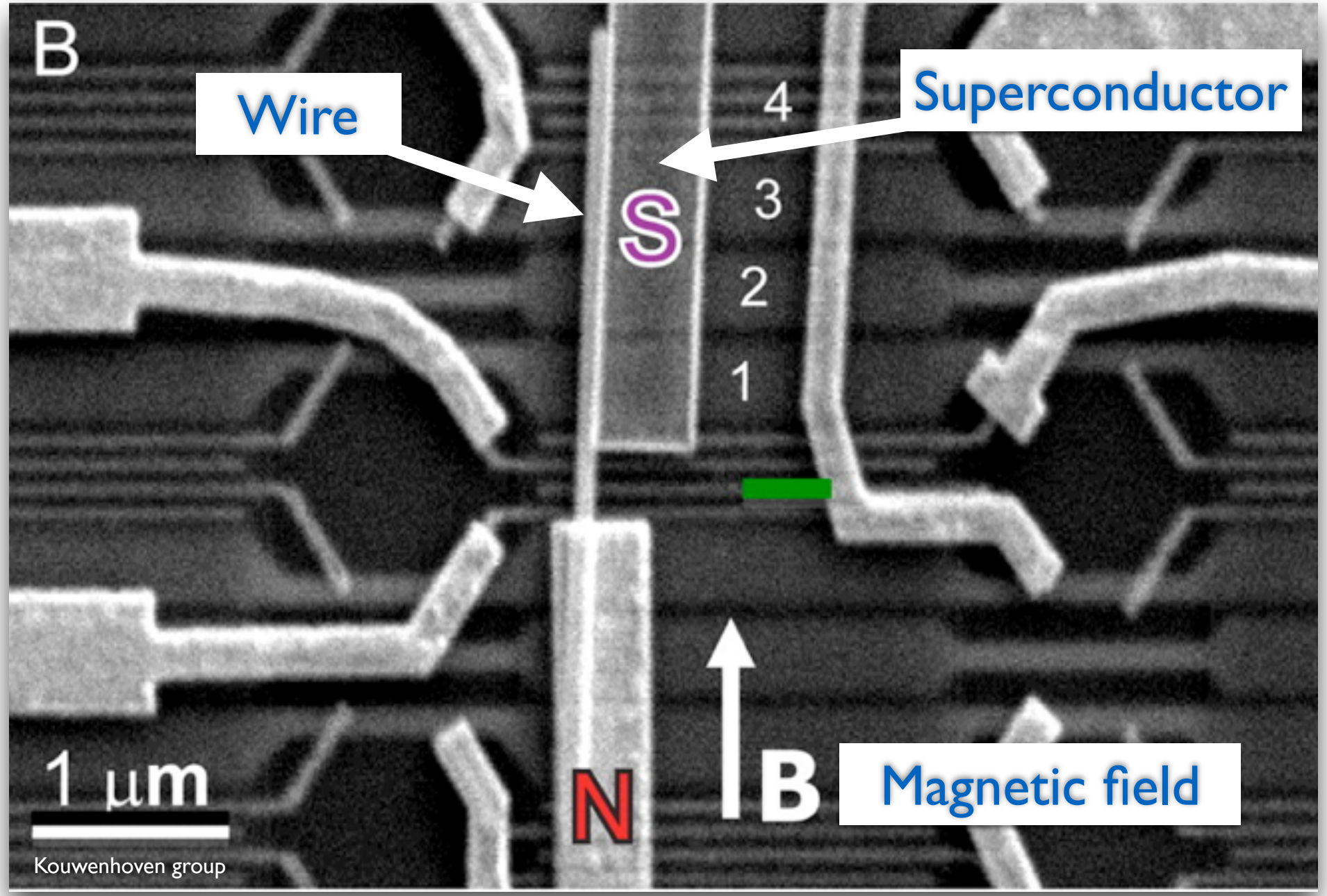
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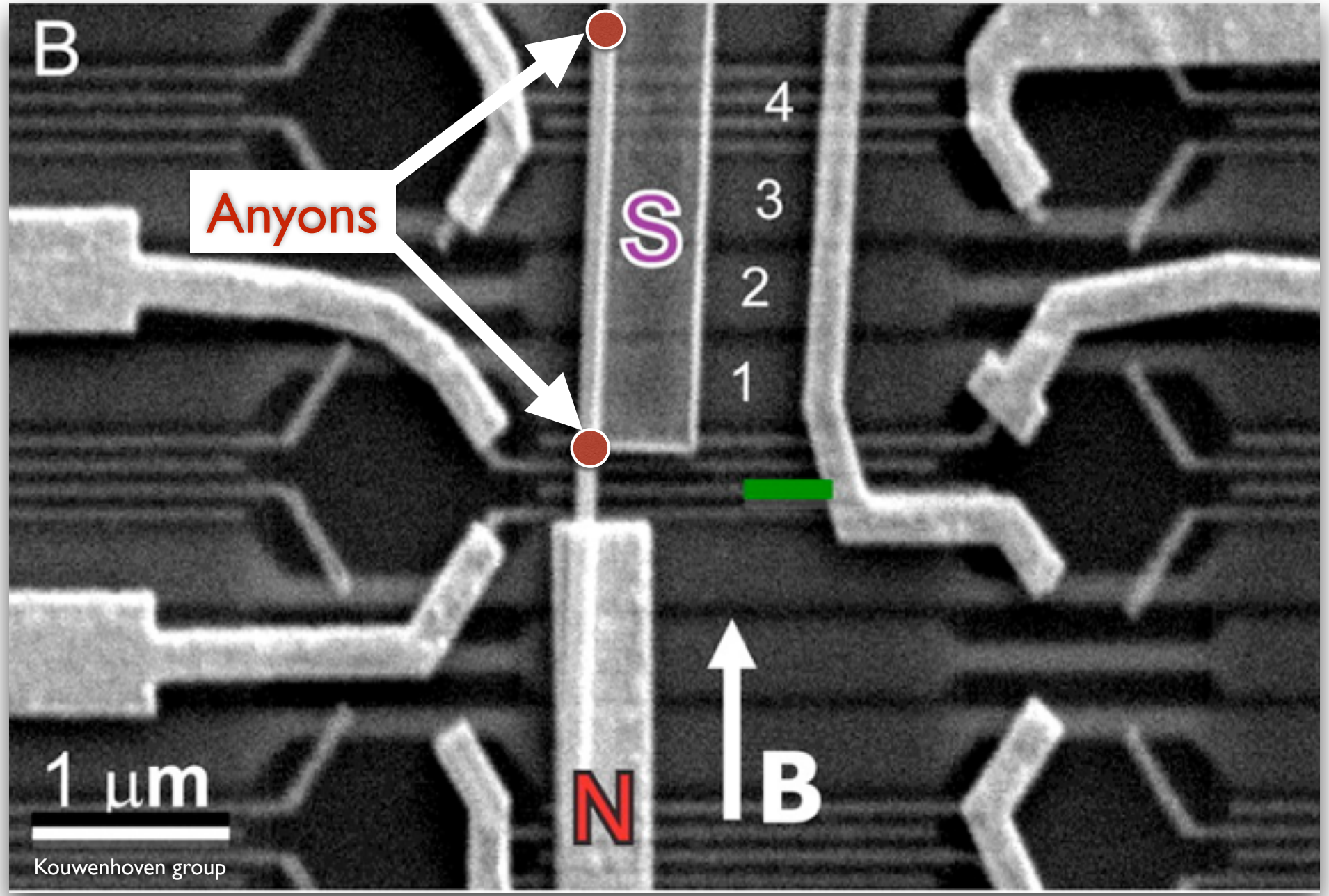
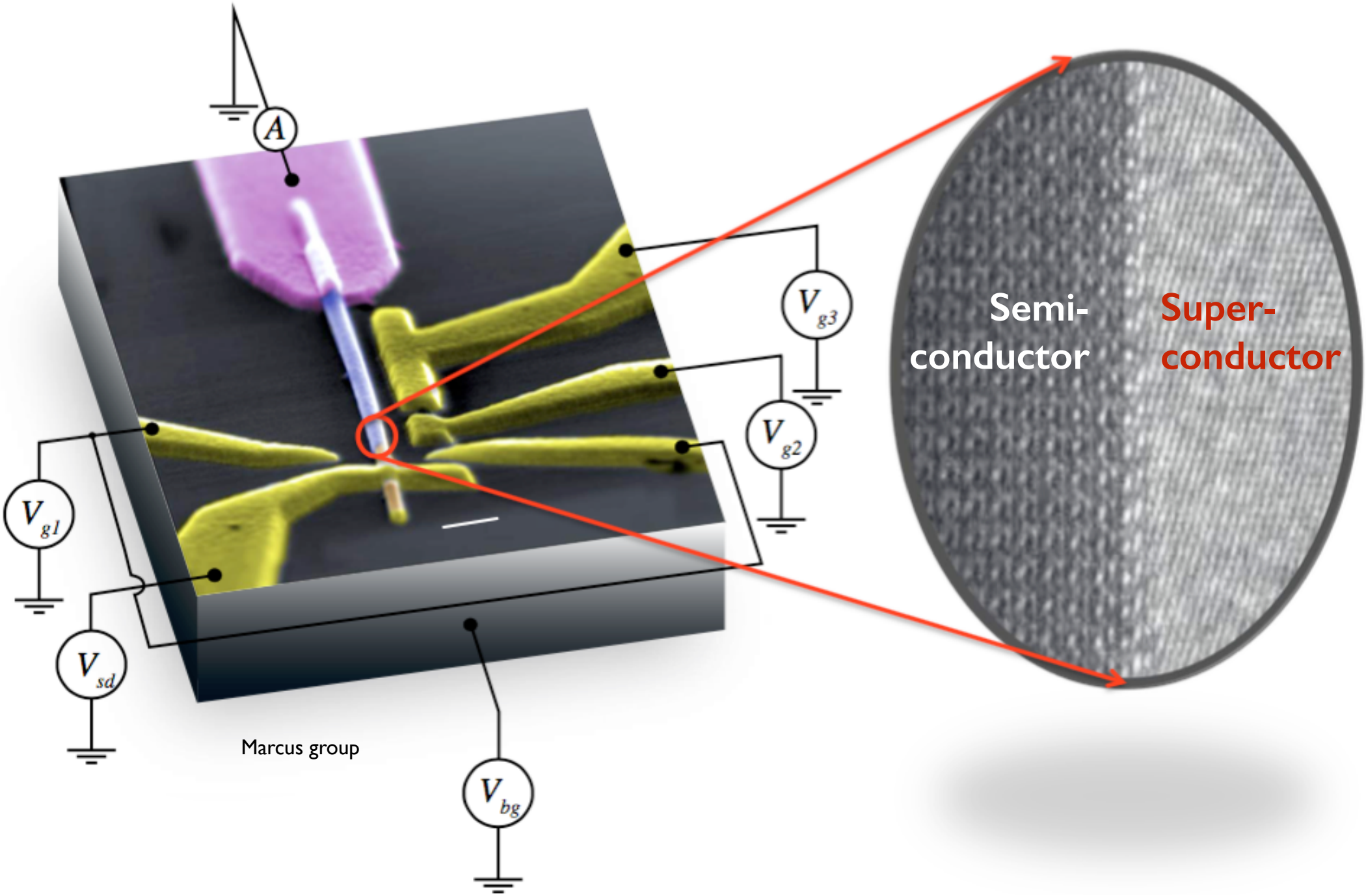
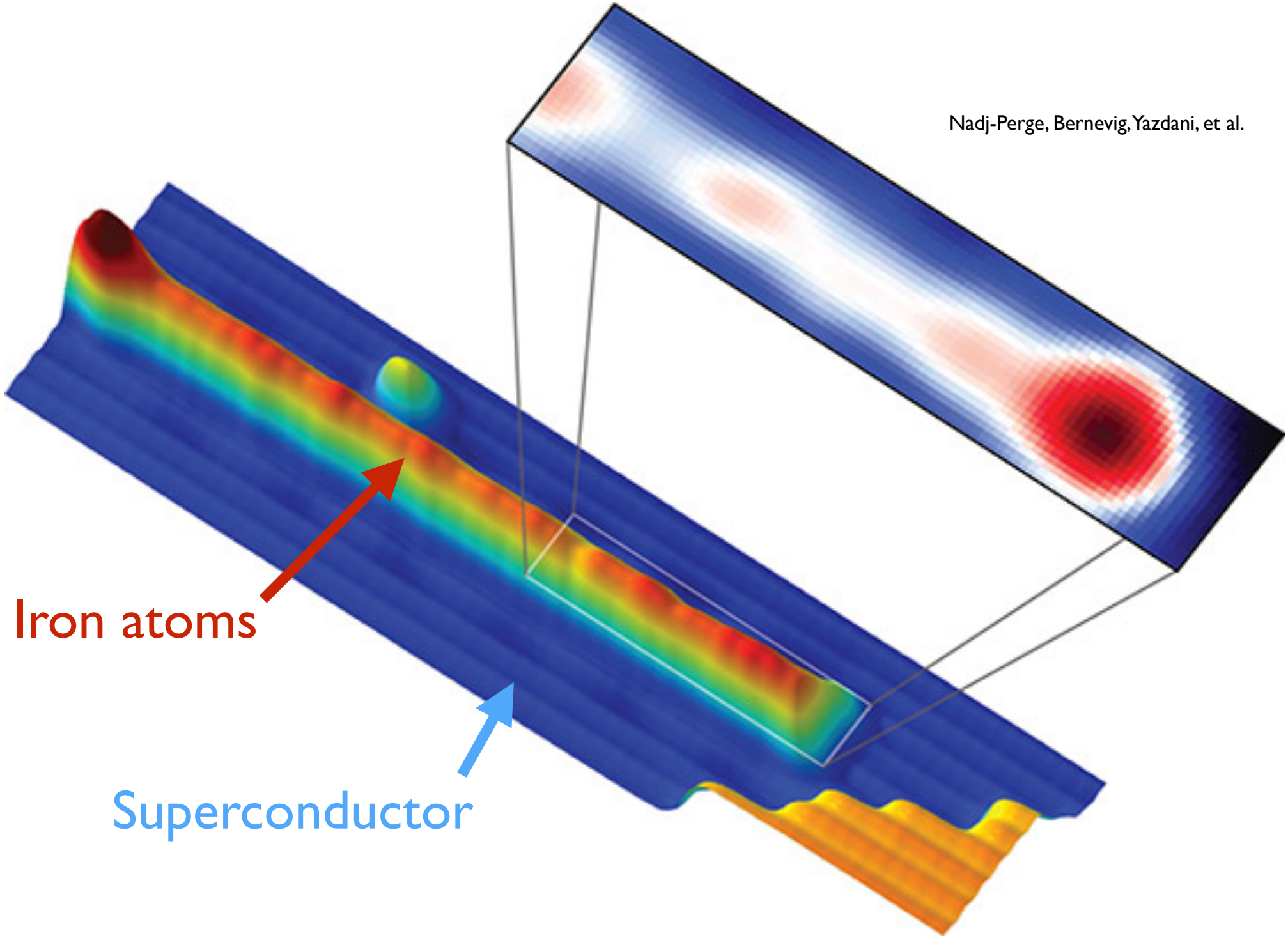
“Majorana modes” ~ half an electron state



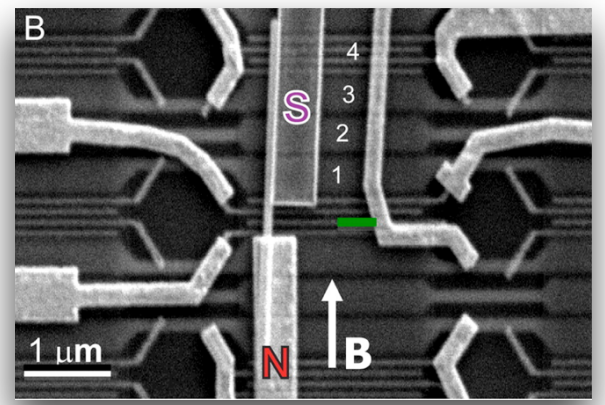


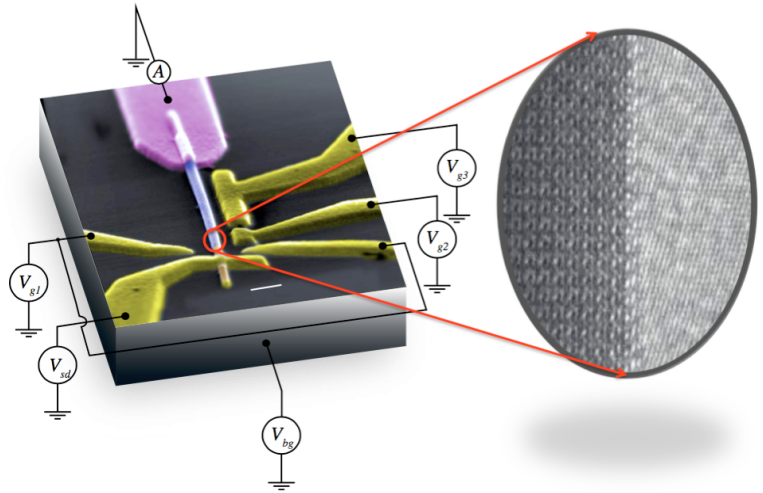
Marcus group

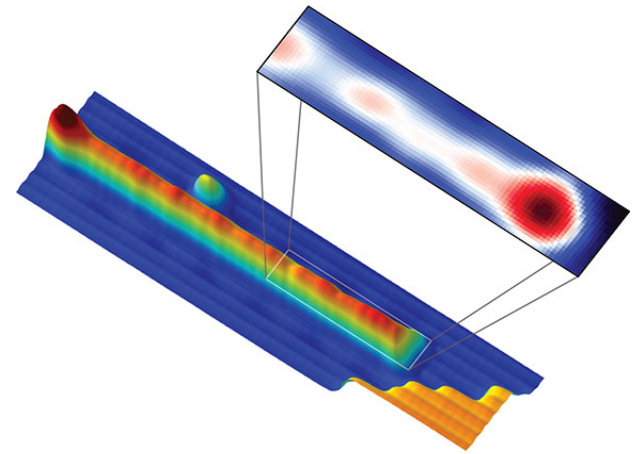
Materials science breakthrough…


Nadj-Perge, Bernevig, Yazdani, et al.
Iron atoms
Superconductor

Compelling Majorana-mode evidence seen in these devices (and more)!







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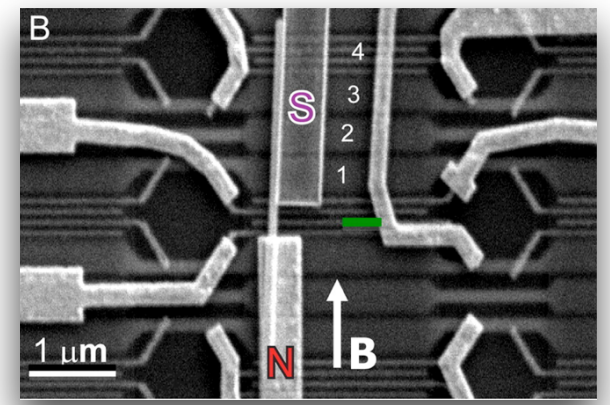

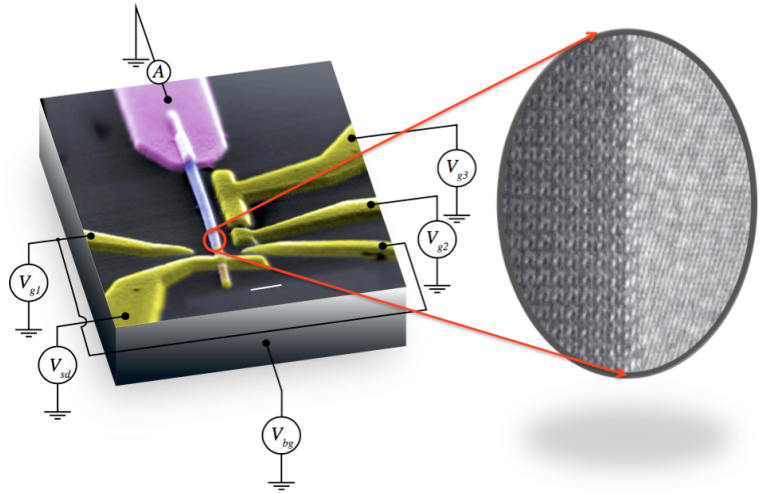

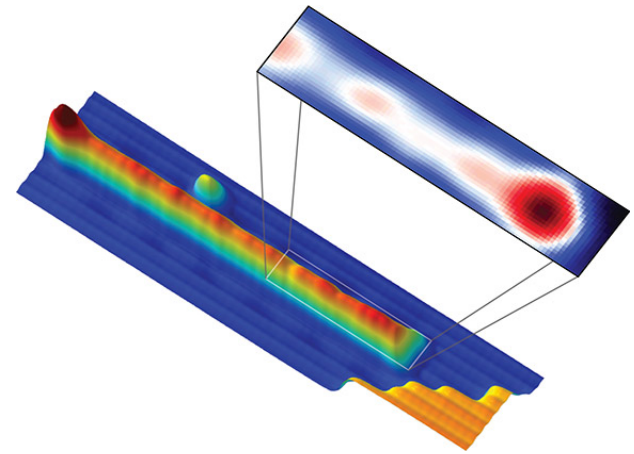

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— SCIENCE http://www.gizmag.com/majorana-fermions-detected/22241/

Majorana fermions – the answer to Life, the Universe, and Everything?

DARIO BORGHINO APRIL 27, 2012

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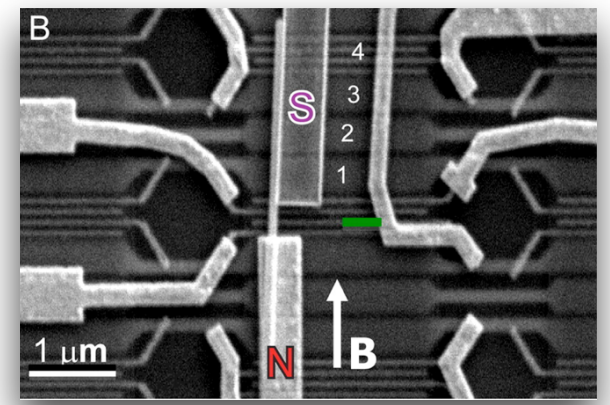

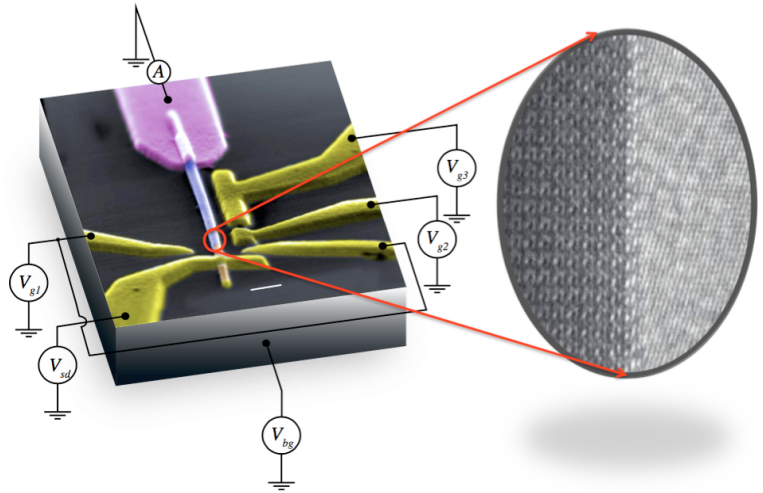

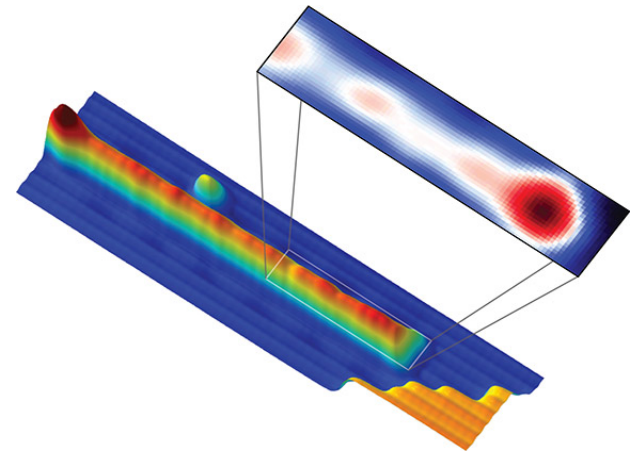

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–No!

DARIO BORGHINO APRIL 27, 2012

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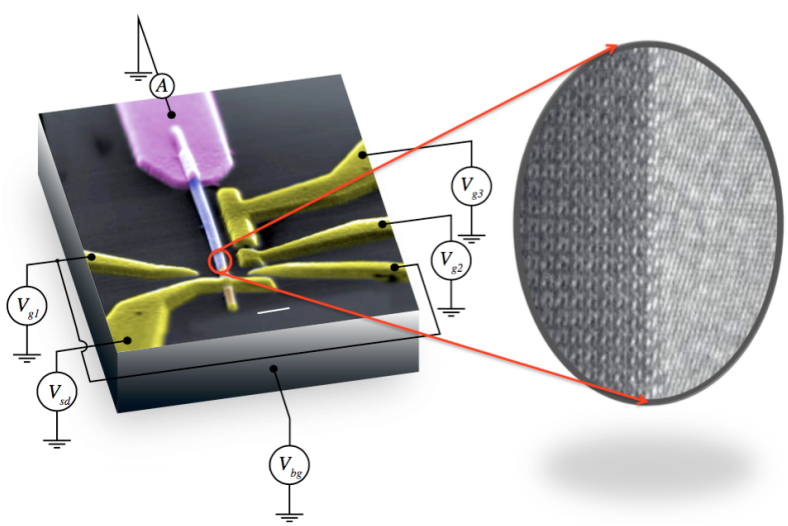
Synthesis & Characterization



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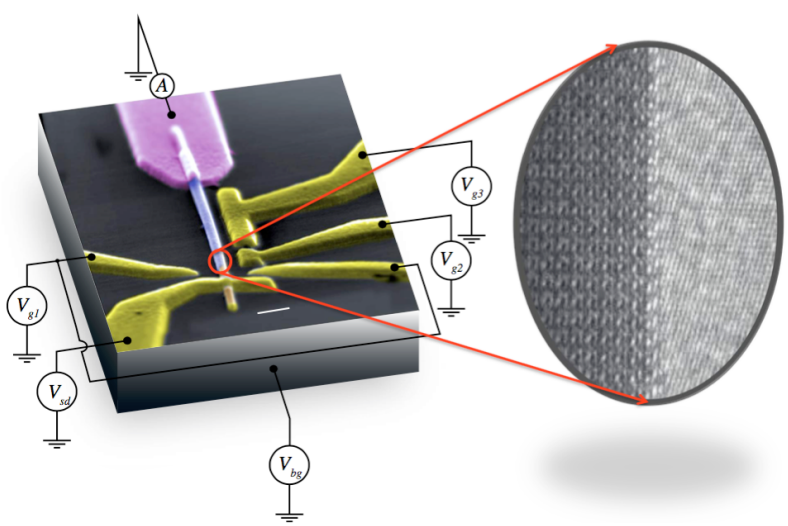
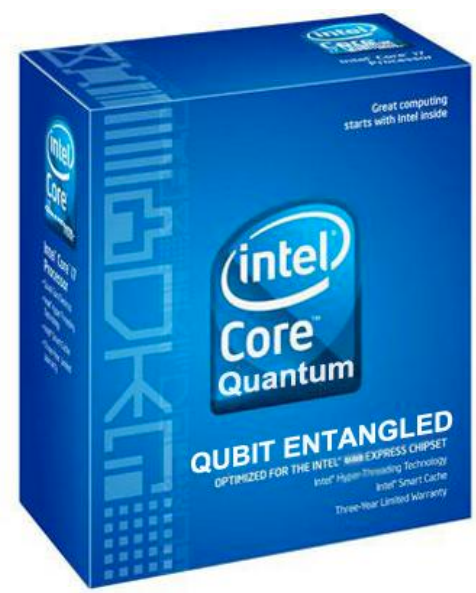


Control



Aasen, Hell, Mishmash, Higginbotham, Danon, Leijnse, Jespersen, Folk, Marcus, Flensberg, JA, arXiv:1511.05153

Nontrivial fusion

Nontrivial fusion

Prototype topological qubit

$$|0\rangle, |1\rangle$$

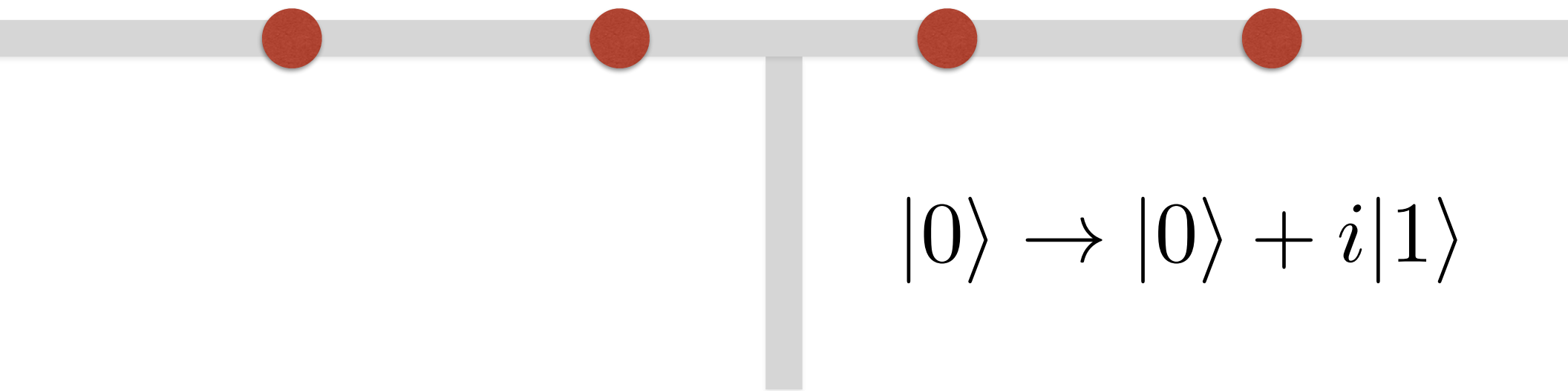
Nontrivial fusion

Prototype topological qubit

Anyon braiding

How quickly can anyons be braided?
Or: How I learned to stop worrying about diabatic errors and love the anyon

Christina Knapp,[1] Michael Zaletel,[2] Dong E. Liu,[2] Meng Cheng,[2] Parsa Bonderson,[2] and Chetan Nayak[2,1]
[1]*Physics Department, University of California, Santa Barbara, California 93106, USA*
[2]*Station Q, Microsoft Research, Santa Barbara, California 93106-6105, USA*



$$|0\rangle \rightarrow |0\rangle + i|1\rangle$$

Nontrivial fusion

Prototype topological qubit

Anyon braiding

How quickly can anyons be braided?
Or: How I learned to stop worrying about diabatic errors and love the anyon

Christina Knapp,[1] Michael Zaletel,[2] Dong E. Liu,[2] Meng Cheng,[2] Parsa Bonderson,[2] and Chetan Nayak[2,1]
[1]*Physics Department, University of California, Santa Barbara, California 93106, USA*
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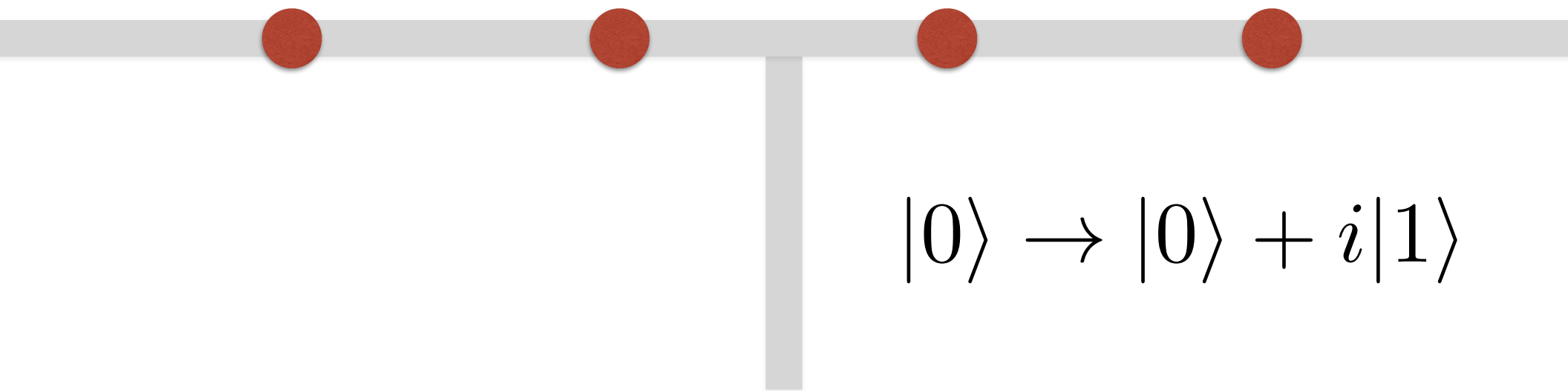

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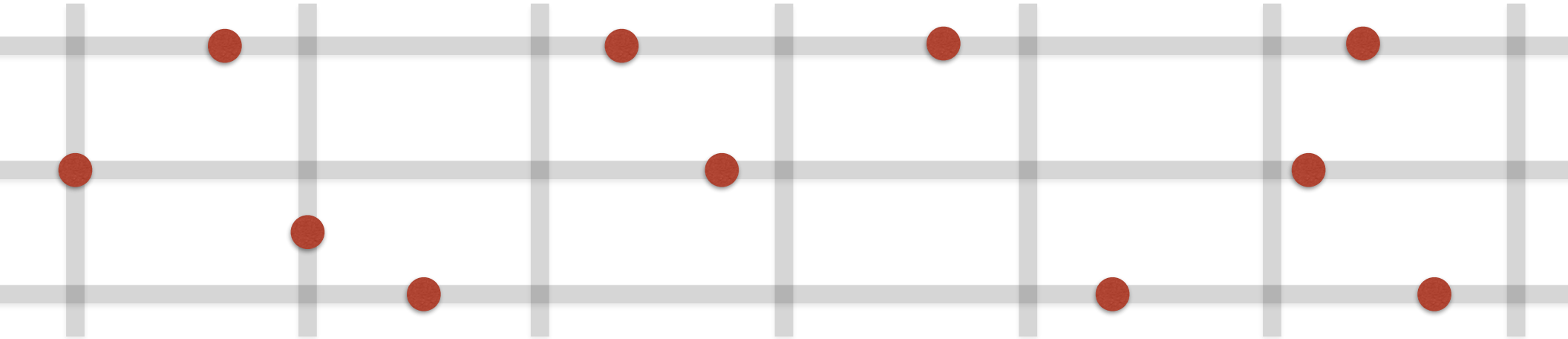

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Love the anyon

On horizon (?):

Verifying basic tenets of topological quantum computing…

…AND demonstrating new fundamental aspects of quantum mechanics