MESOSCOPIC PHYSICS

Nontopological zero-bias peaks in full-shell nanowires induced by flux-tunable Andreev states

Marco Valentini[1]*, Fernando Peñaranda[2], Andrea Hofmann[1]†, Matthias Brauns[1]‡, Robert Hauschild[1], Peter Krogstrup[3], Pablo San-Jose[2], Elsa Prada[2,4], Ramón Aguado[2]*, Georgios Katsaros[1]*

A semiconducting nanowire fully wrapped by a superconducting shell has been proposed as a platform for obtaining Majorana modes at small magnetic fields. In this study, we demonstrate that the appearance of subgap states in such structures is actually governed by the junction region in tunneling spectroscopy measurements and not the full-shell nanowire itself. Short tunneling regions never show subgap states, whereas longer junctions always do. This can be understood in terms of quantum dots forming in the junction and hosting Andreev levels in the Yu-Shiba-Rusinov regime. The intricate magnetic field dependence of the Andreev levels, through both the Zeeman and Little-Parks effects, may result in robust zero-bias peaks—features that could be easily misinterpreted as originating from Majorana zero modes but are unrelated to topological superconductivity.

Presenter: Omid SHARIFI SEDEH
Date: 03.09.2021

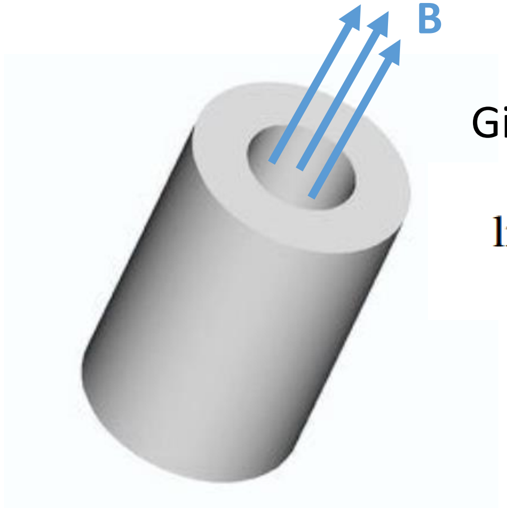
Little-Parks Effect:

Oscillation of Superconducting critical temperature
As a function of magnetic field with period of ϕ_0

Destructive little-Parks effect is only possible if superconducting coherent length> d

The thickness d affects the Little-Parks effect enormously.

When cooper pair kinetic energy exceeds superconducting condensation energy→ fully suppression of superconductivity



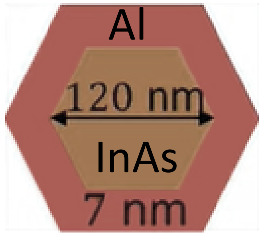
Superconducting cylinder

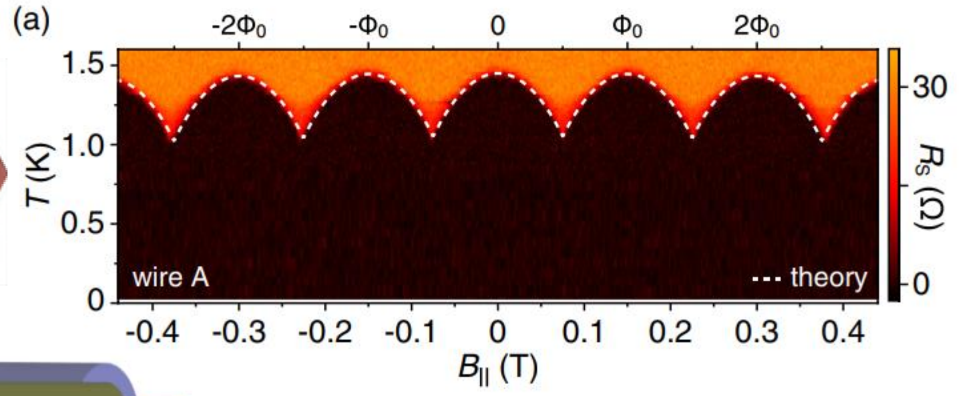
Ginzburg Landau mean field theory

$$\ln\left(\frac{T_C(\alpha)}{T_{C0}}\right) = \Psi\left(\frac{1}{2}\right) - \Psi\left(\frac{1}{2} + \frac{\alpha}{2\pi k_B T_C(\alpha)}\right),$$

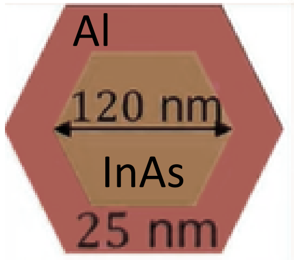
All this Leads to the same Oscillations in Conductance →

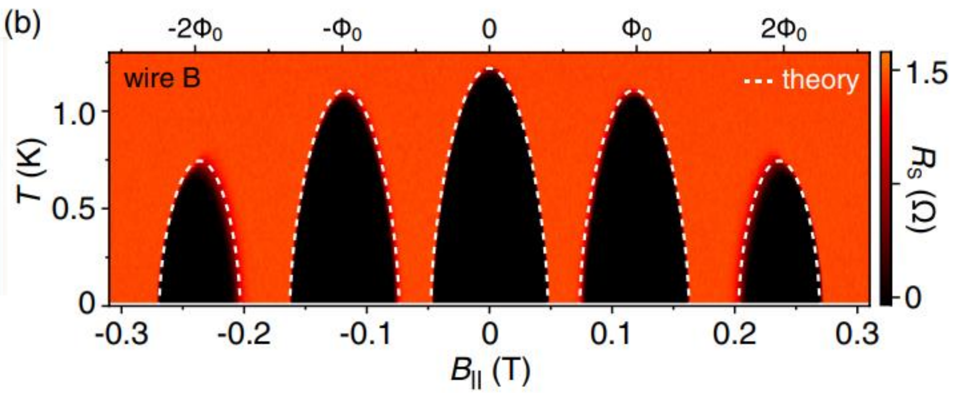
Weak Little-Parks effect

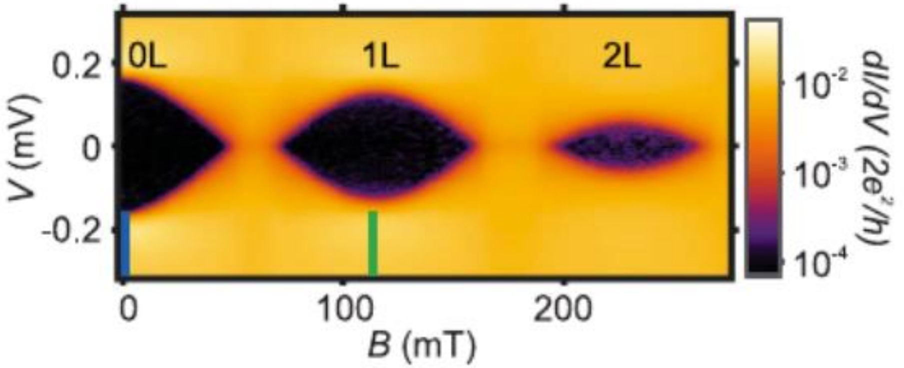




Destructive Little Parks effect







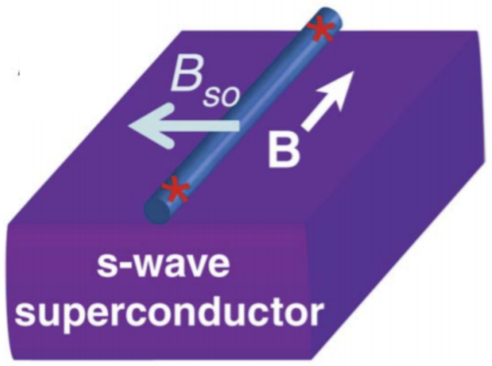
PHYSICAL REVIEW B **101**, 060507(R) (2020)

Proposal for Realization of Majorana states in 1D systems

One-dimensional Spinless p-wave superconductor

Effctively

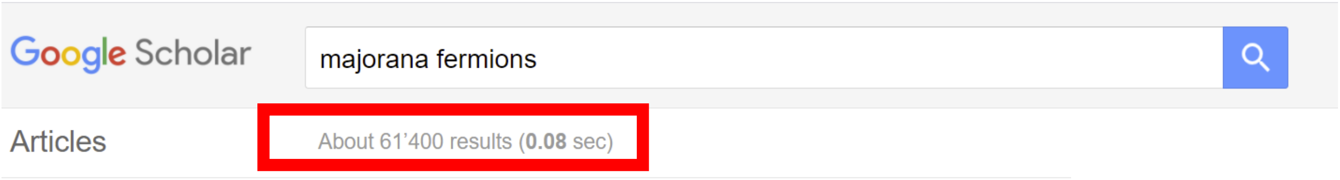
- 1D nanowire with spin-orbit interaction
- Proximity with an s-wave superconductor
- Applying magnetic field along the nanowire (perpendicular to B_{so})



10.1126/science.1222360

For $E_Z > E_c$ ⟶ topological phase transition ⟶ 2 unpaired Majorana states at 2 ends of Nanowire

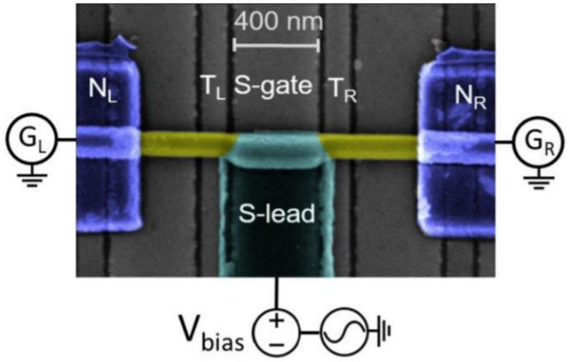
Many attempts in realizing MZMs



Important paper on 2020
Casting doubt on all previous claims on MZM discoveries

Non-Majorana states yield nearly quantized conductance in superconductor-semiconductor nanowire devices

P. Yu, J. Chen, M. Gomanko, G. Badawy, E.P.A.M. Bakkers, K. Zuo, V. Mourik, S.M. Frolov



Theoretical proposals and predictions for using full shell nanowires:

Topological superconductivity in full shell proximitized nanowires

(Dated: September 17, 2018)

Roman M. Lutchyn,[1] Georg W. Winkler,[1] Bernard van Heck,[1] Torsten Karzig,[1] Karsten Flensberg,[2] Leonid I. Glazman,[3] and Chetan Nayak[1]

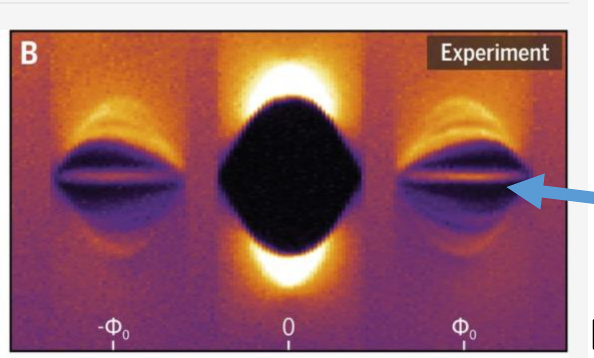
Benefits:

1. Very low magnetic field ~100 mT for the topological transitions:
   field induced winding of Δ rather than Zeeman effect
   → **no need for high g-factor materials**

2. Protects the semiconductor from impurities and random surface doping
   → **Resulting in essentially identical electrostatic environments**.

Problems:

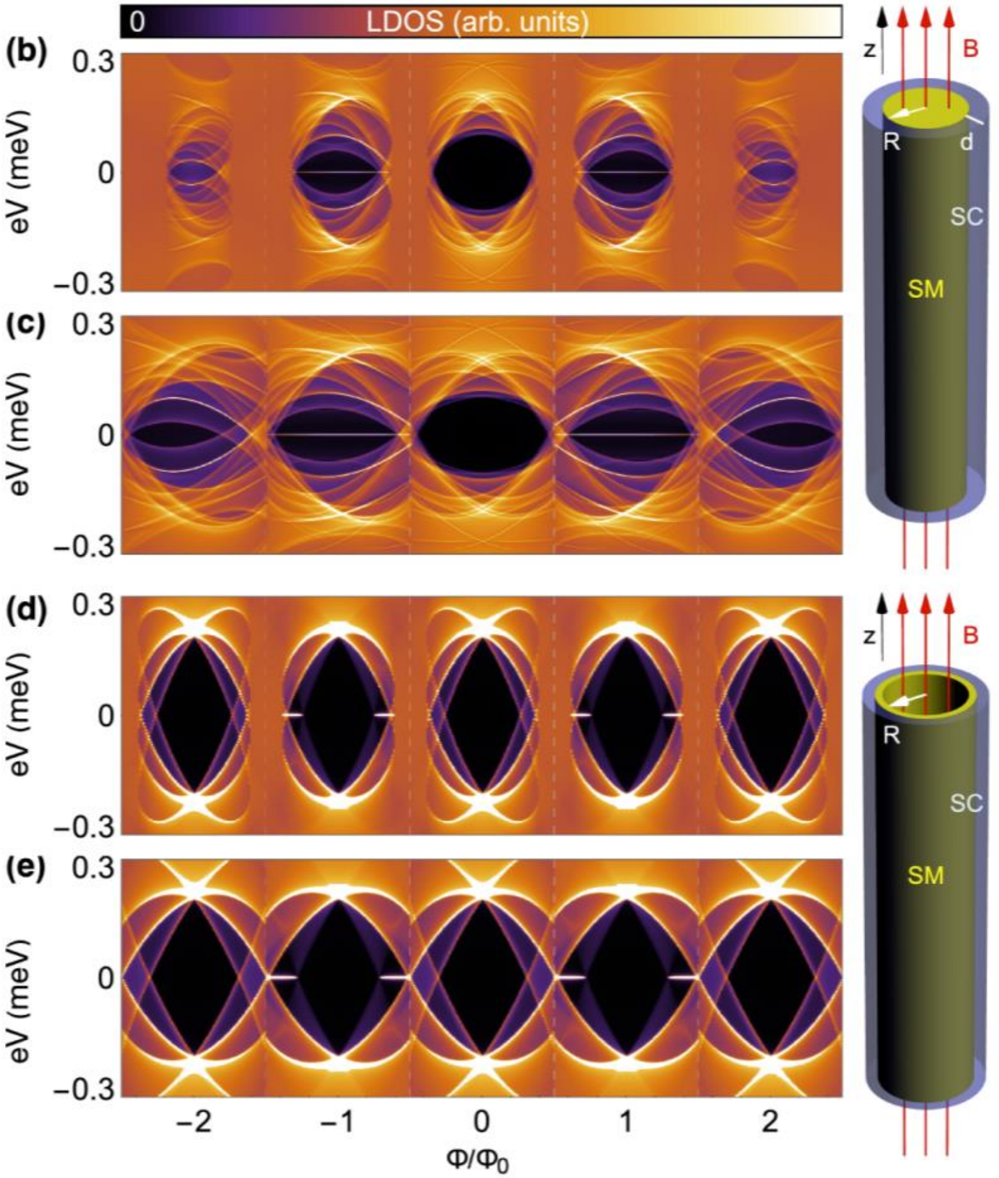
1. No direct gating of the electron density inside the semiconductor



Majorana?

DOI: 10.1126/science.aav3392

Majorana zero modes appear in the odd lobes



PHYSICAL REVIEW RESEARCH 2, 023171 (2020)

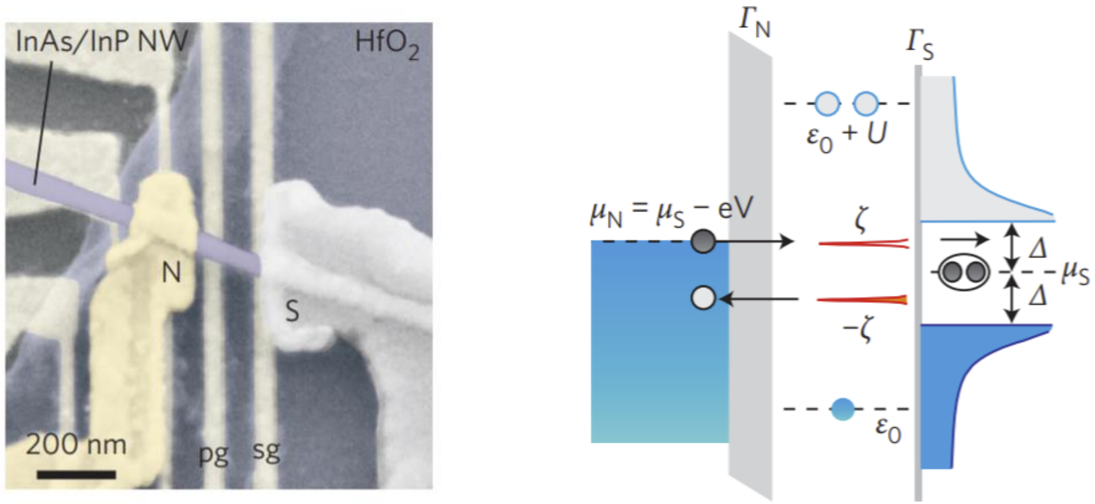
The Biggest obstacle in Majorana detection:
Andreev bound states mimic Majorana signatures

Therefore many studies have been devoted to ABS in similar systems,
i.e. esp. N-QD-S systems:

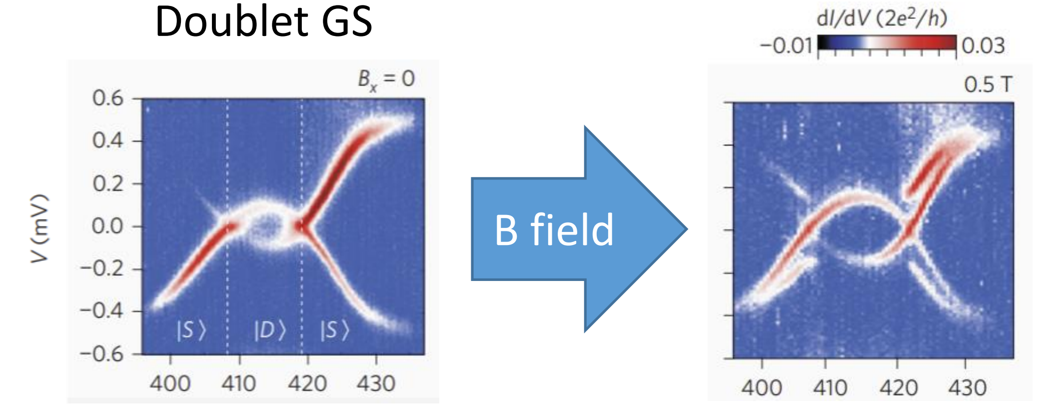
nature nanotechnology | ARTICLES
PUBLISHED ONLINE: 15 DECEMBER 2013 | DOI: 10.1038/NNANO.2013.267

Spin-resolved Andreev levels and parity crossings in hybrid superconductor–semiconductor nanostructures

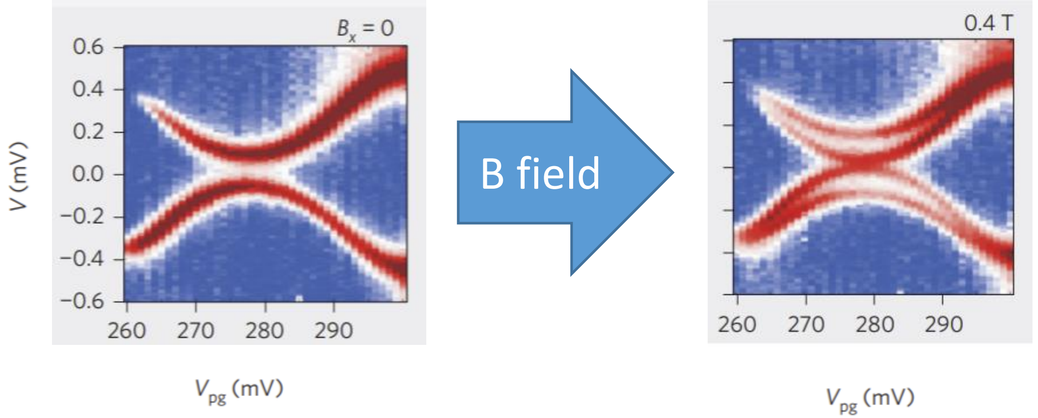
Eduardo J. H. Lee[1], Xiaocheng Jiang[2], Manuel Houzet[1], Ramón Aguado[3], Charles M. Lieber[2] and Silvano De Franceschi[1]*



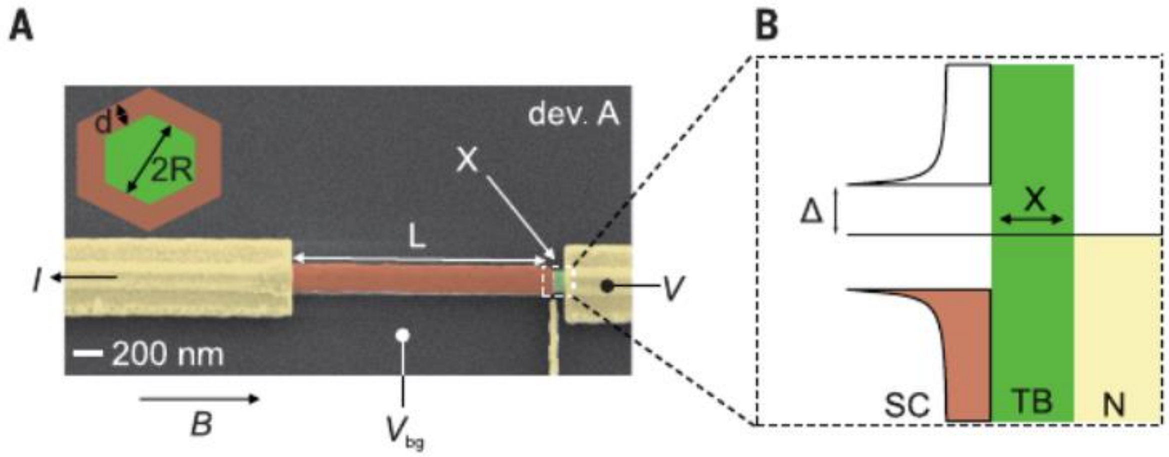
Doublet GS



Singlet GS



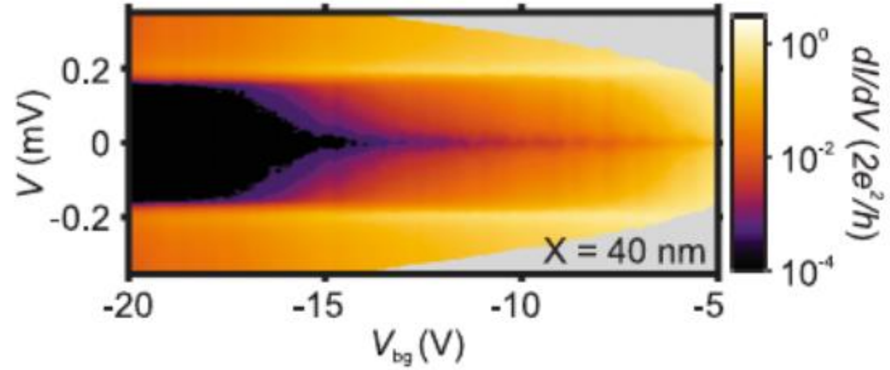
Device:



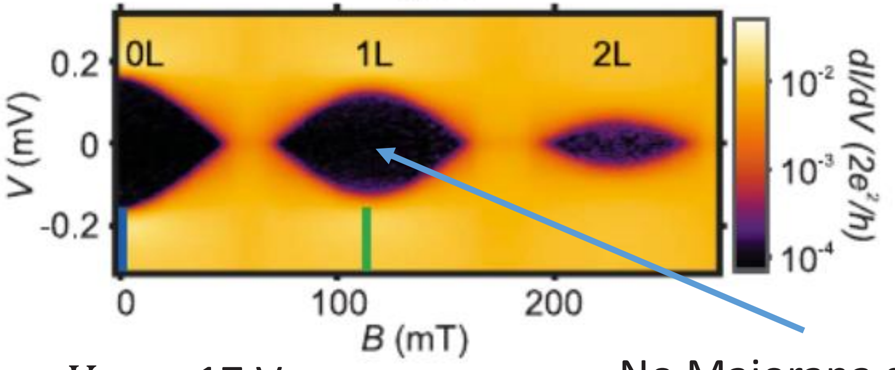
Name of the device	R [nm]	d [nm]	ξ [nm]
A	64	24	160
A2	60	28	150
F	60	28	165
G	61	29	150
H	67	23	160
I	66	21	165
J	60	28	175
K	66	21	165
L	60	27	160
M	60	29	175

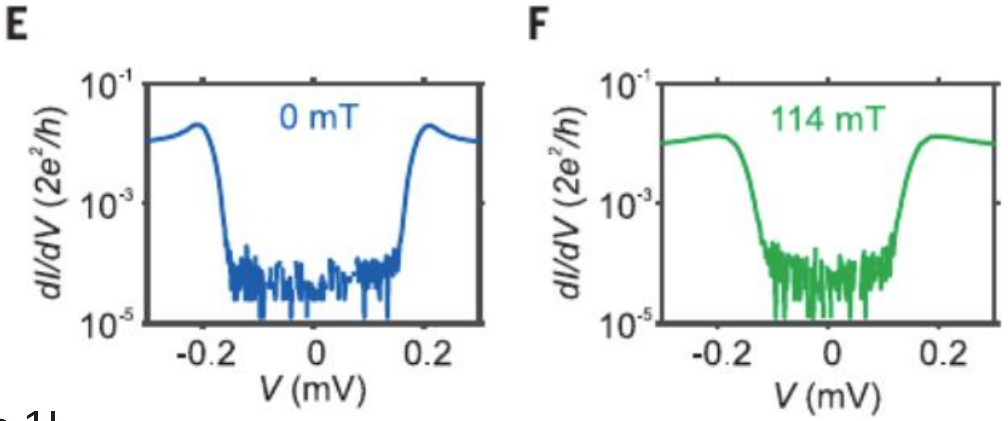
- Hexagonal InAs NWs
- diameter ~ 120 nm
- VLS technique with 30 nm Al shell epitaxially grown in situ,
- The NWs were deposited on a heavily doped silicon substrate covered with 285 nm of silicon oxide
- The gates and contacts 5 nm/180 nm Ti/Au bilayer
- measured via a lock-in technique in a dilution refrigerator with a base temperature of 20 mK.

Short Junction devices (X<100 nm):



Experiments on over 40 devices:
no QD is formed in the bare InAs NW for X <100 nm





V_{bg}= −17 V

No Majorana signature in the 1L

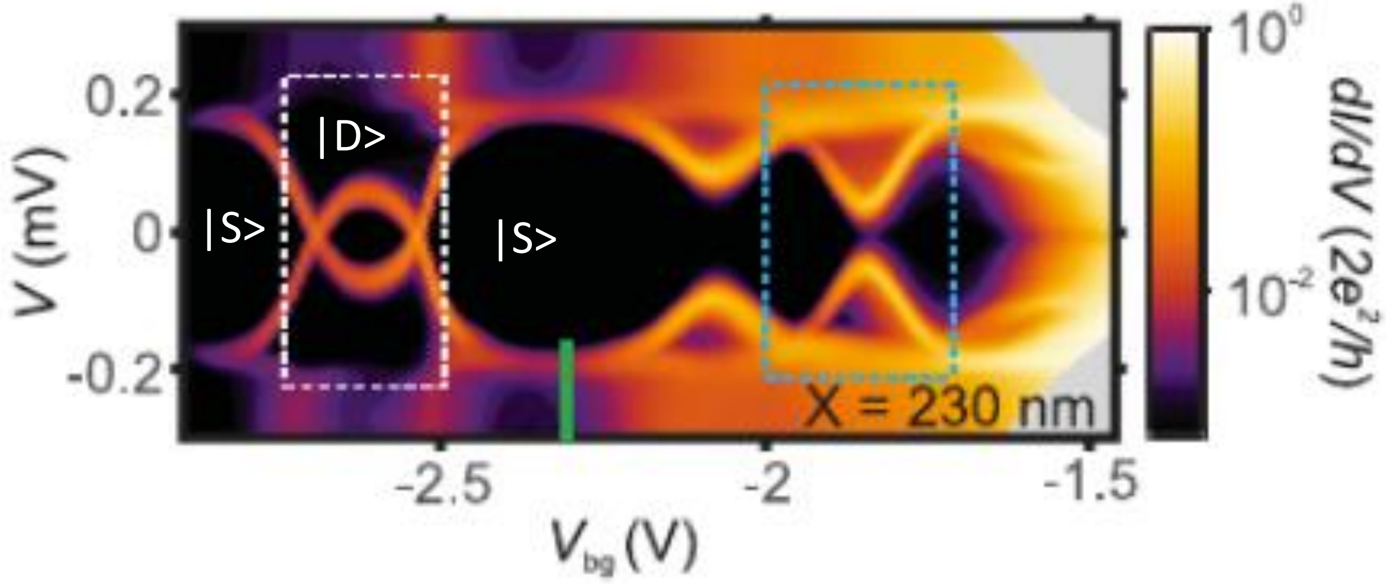
Short-junction results seemingly contradict recent experimental report on MZMs in similar NWs (
S. Vaitiekėnas et al., Science 367, eaav3392 (2020)).

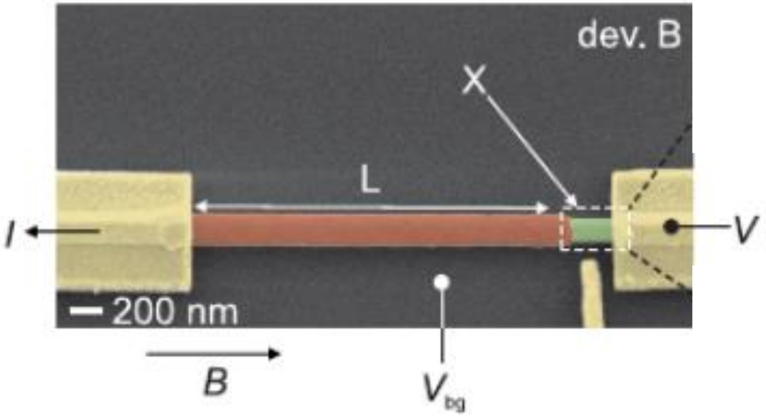
Important conclusion: Short Junction devices are the best for realizing the MZMs.

Long Junction devices (X>150 nm):

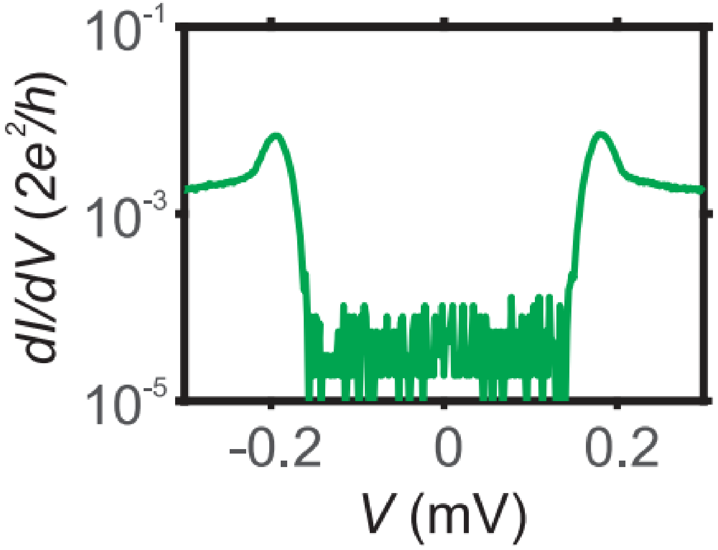
a QD forms in the tunnel junction

B=0





Dev. B with X ≈ 240 nm
QD Charging energy U ≈ 2.5 meV

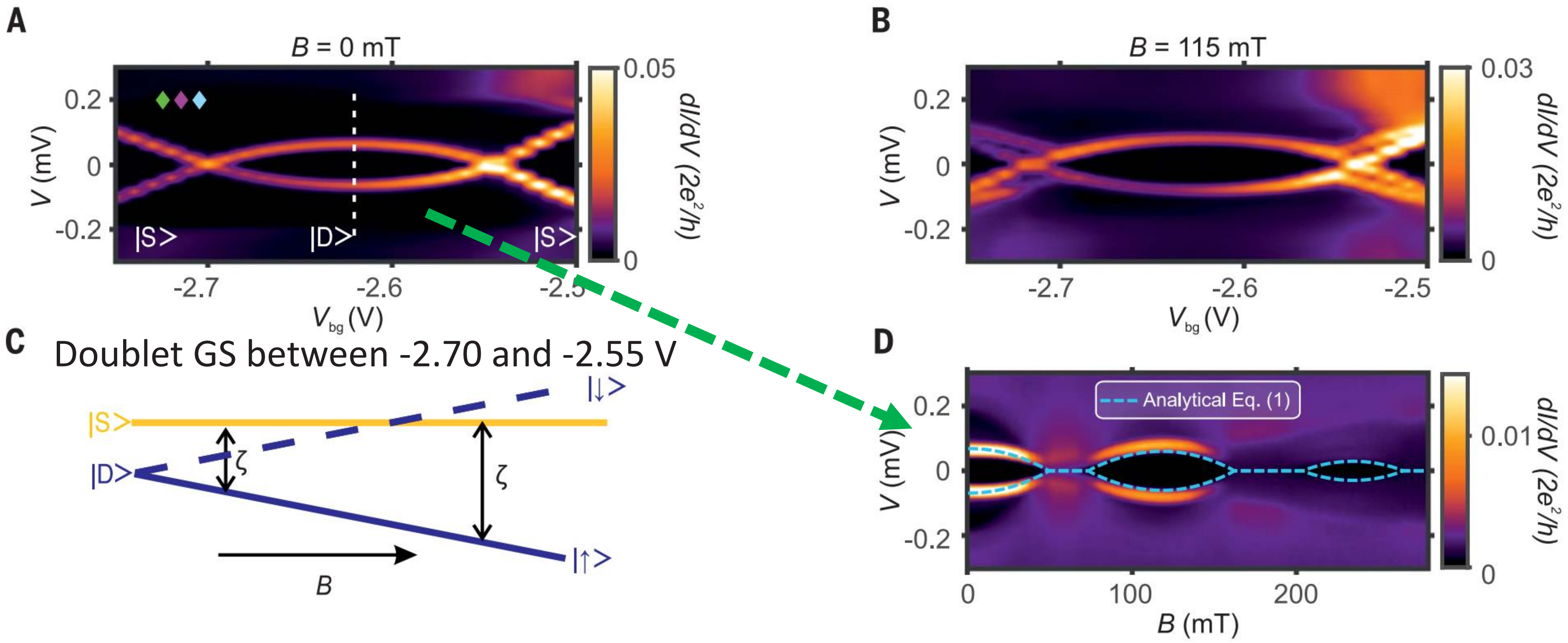


Andreev bound states are in YSR regime:
Charging energy (2.5 meV) >> Δ (0.2meV)

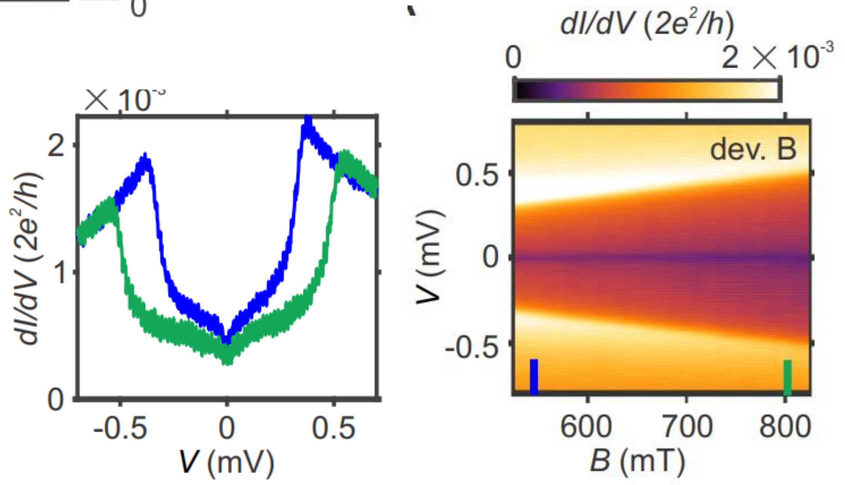
In the small Δ/U limit, the unpaired spin in the QD couples to the quasiparticles in the SC, with an exchange interaction $J \sim 2\Gamma_s/U$. This exchange interaction creates so-called Yu-Shiba-Rusinov (YSR) singlets.

Zoomed-in of the Doublet GS region

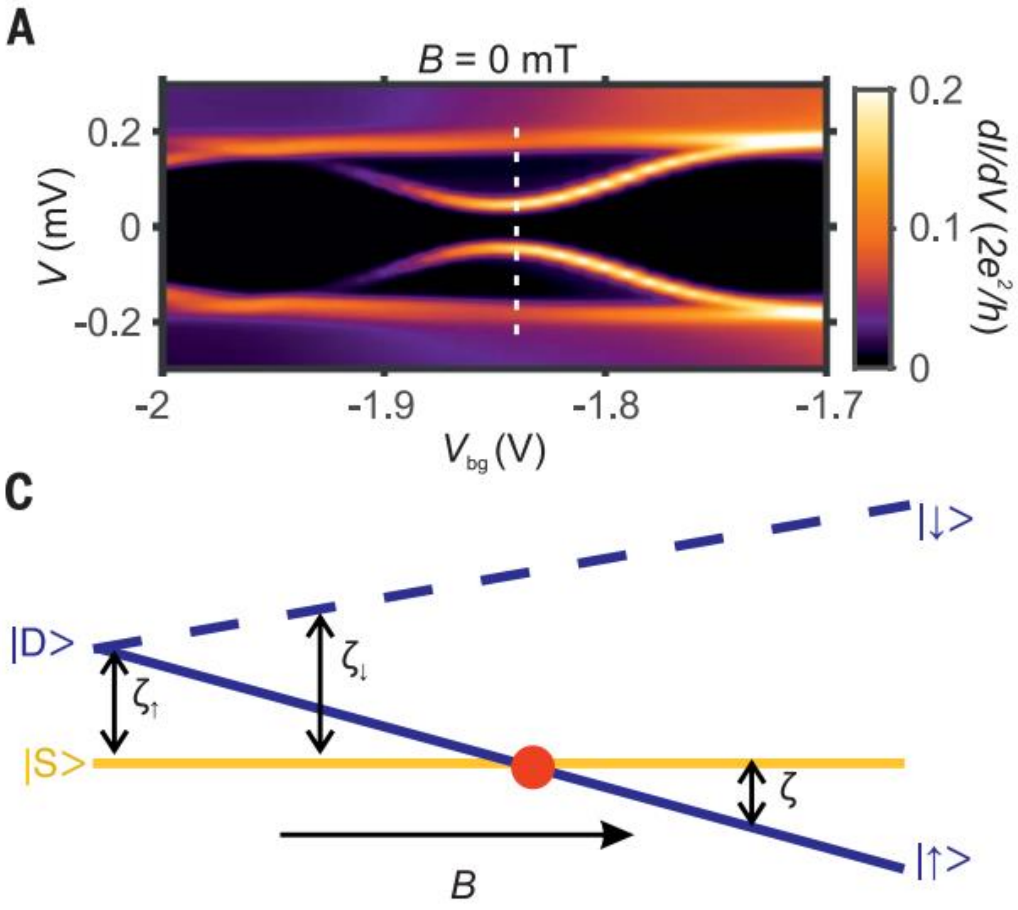
The spin polarized doublet states change their energy with B by the Zeeman energy whereas the excited singlet energy remains unaffected



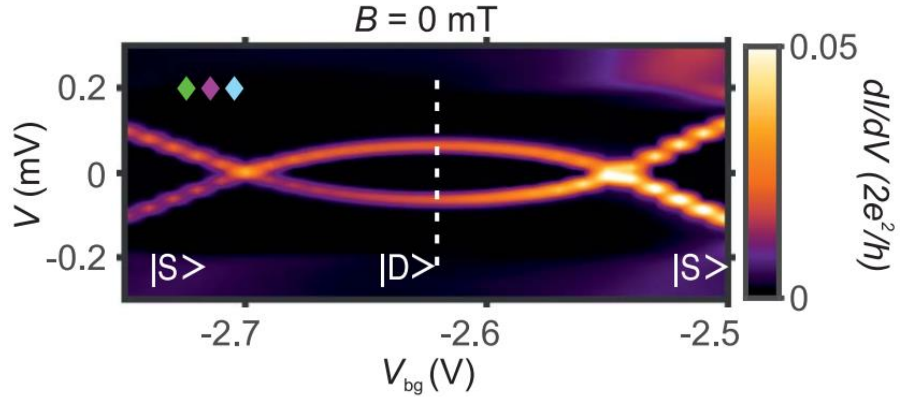
Supplementary material:
A g-factor of ~10 was extracted by following the Kondo split peak

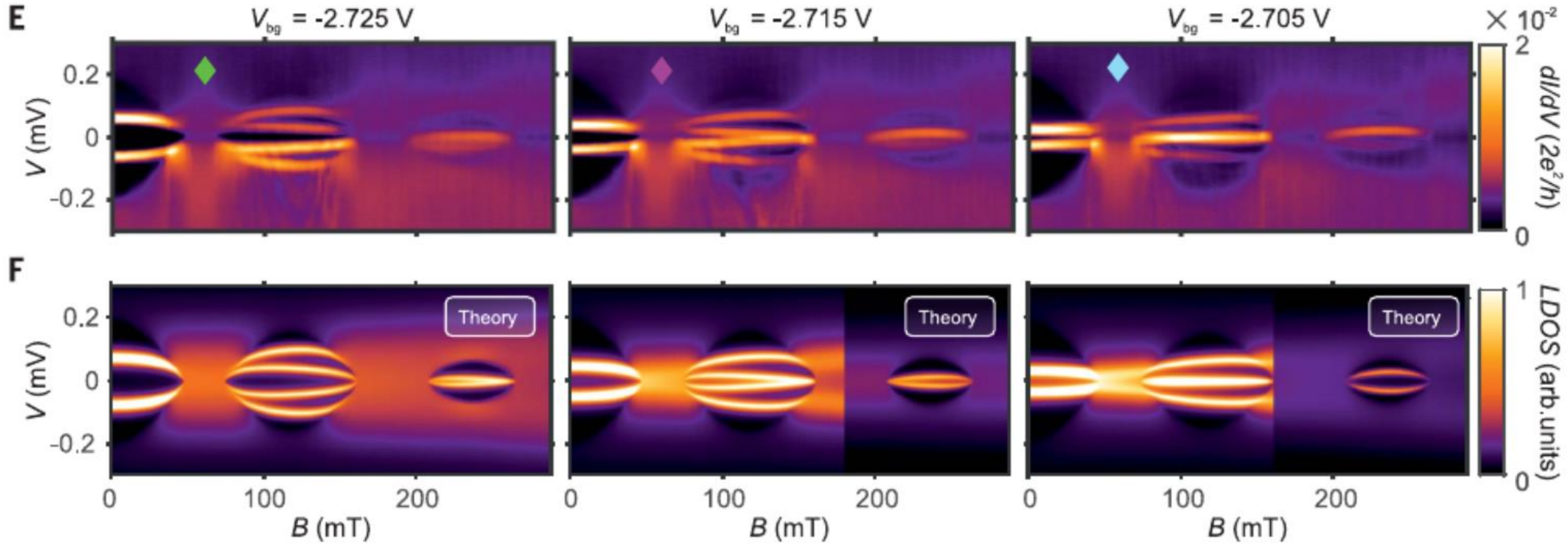


Magnetic field evolution of ABSs with a singlet GS:

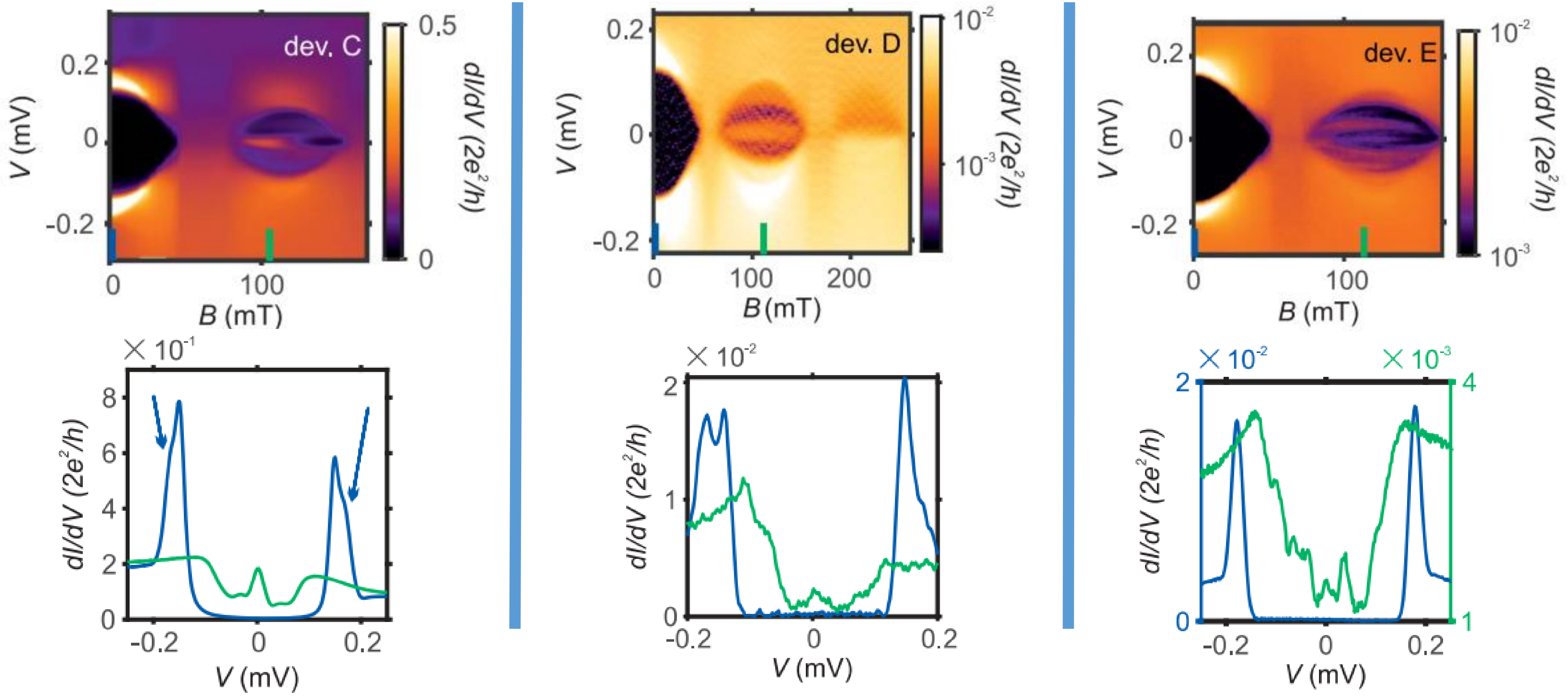


Is it possible to have the Zero bias peak in the 1st lobe?



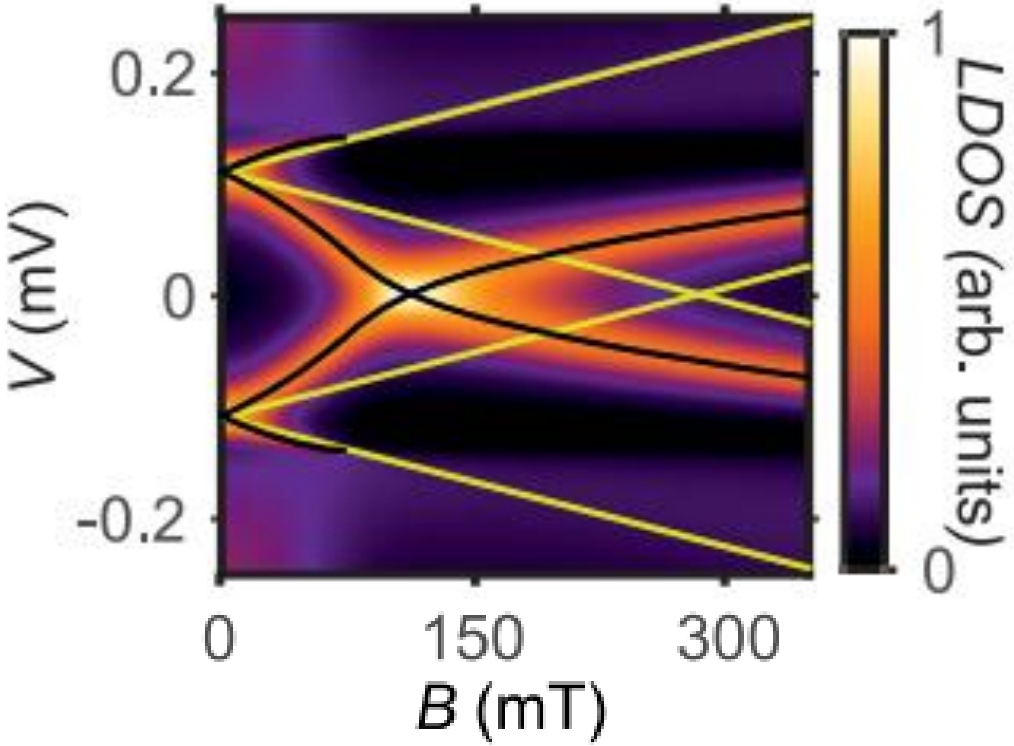


Devices with ZBPs without an apparent subgap structure in the zeroth lobe

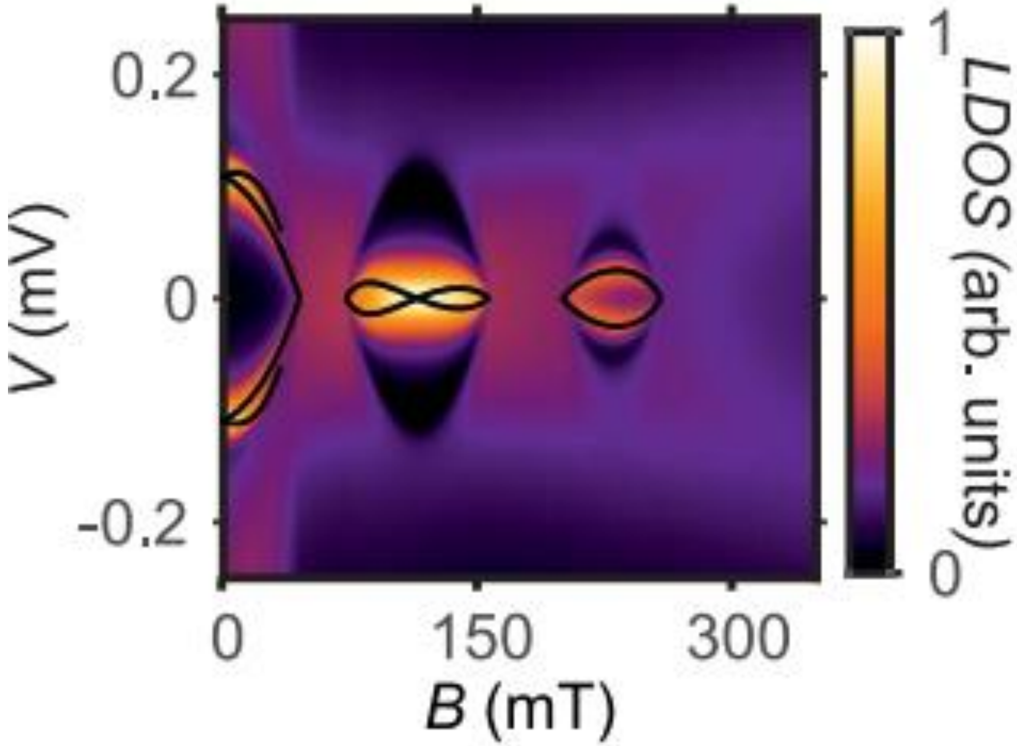


Simulation Notes:

Constant Δ



$\Delta(\Phi)$



Conclusion:

- No MZMs were observed in neither of about 40 devices in none of the junction limits
- Short junction devices are the best for realizing the MZMs

Thanks for your attention

More about the Wires:

LETTERS

PUBLISHED ONLINE: 12 JANUARY 2015 | DOI: 10.1038/NNANO.2014.306

nature nanotechnology

Hard gap in epitaxial semiconductor–superconductor nanowires

W. Chang[1,2], S. M. Albrecht[1], T. S. Jespersen[1], F. Kuemmeth[1], P. Krogstrup[1], J. Nygård[1] and C. M. Marcus[1]*

Epitaxy of semiconductor–superconductor nanowires

P. Krogstrup[1]*, N. L. B. Ziino[1], W. Chang[1], S. M. Albrecht[1], M. H. Madsen[1], E. Johnson[1,2], J. Nygård[1,3]*, C. M. Marcus[1] and T. S. Jespersen[1]*

Controlling the properties of semiconductor/metal interfaces is a powerful method for designing functionality and improving the performance of electrical devices. Recently semiconductor/superconductor hybrids have appeared as an important example where the atomic scale uniformity of the interface plays a key role in determining the quality of the induced superconducting gap. Here we present epitaxial growth of semiconductor-metal core-shell nanowires by molecular beam epitaxy, a method that provides a conceptually new route to controlled electrical contacting of nanostructures and the design of devices for specialized applications such as topological and gate-controlled superconducting electronics. Our materials of choice, InAs/Al grown with epitaxially matched single-plane interfaces, and alternative semiconductor/metal combinations allowing epitaxial interface matching in nanowires are discussed. We formulate the grain growth kinetics of the metal phase in general terms of continuum parameters and bicrystal symmetries. The method realizes the ultimate limit of uniform interfaces and seems to solve the soft-gap problem in superconducting hybrid structures.