

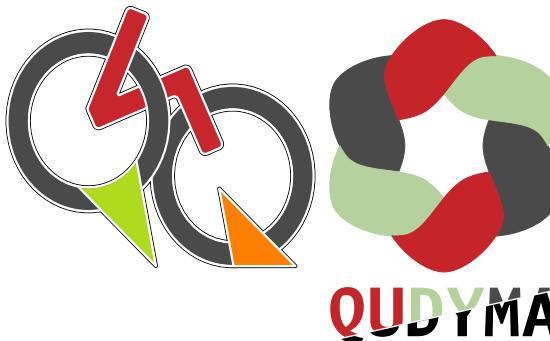
# Josephson effect in full-shell hybrid nanowires

Carlos Payá

APS Global Physics Summit – March 18<sup>th</sup>, 2025



**CSIC**

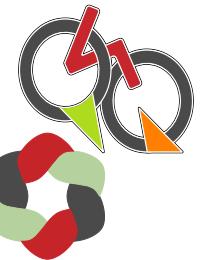


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**icmm**

# About us

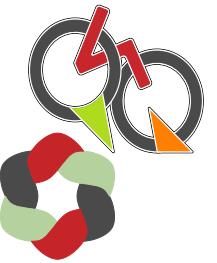
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***Josephson effect and critical currents in trivial and topological full-shell hybrid nanowires***  
C. Payá, R. Aguado, P. San-Jose and E. Prada  
arXiv:2503.09756



***Phenomenology of Majorana zero modes in full-shell hybrid nanowires***  
C. Payá, S. D. Escrivano, A. Vezzosi,  
F. Peñaranda, R. Aguado, P. San-Jose and E. Prada  
Phys. Rev. B **109**, 115428



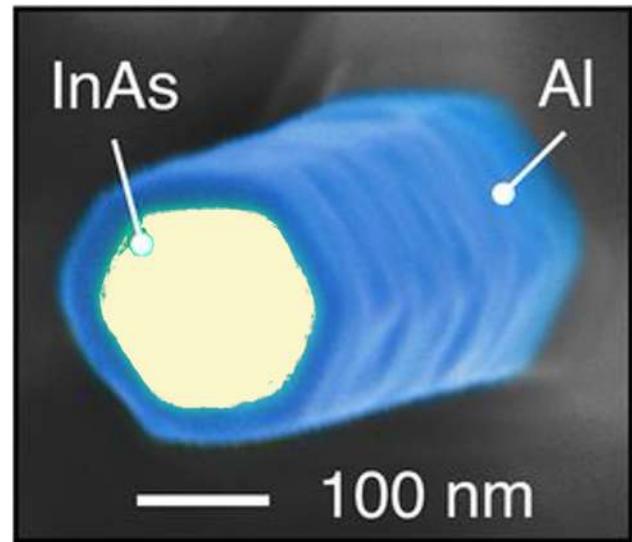
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What does the **critical current** of a full-shell Josephson junction look like?

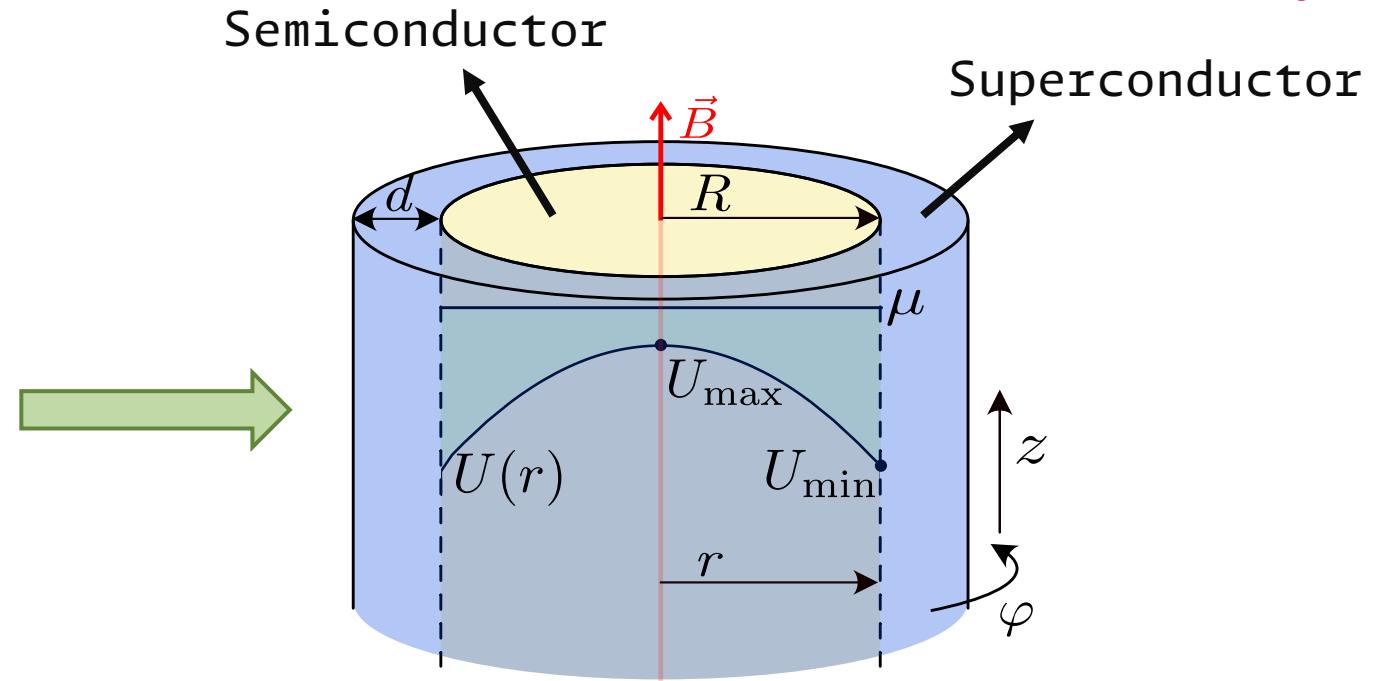
How do **non-topological** sub-gap states contribute?

What about **Majoranas**?

# A full-shell hybrid nanowire



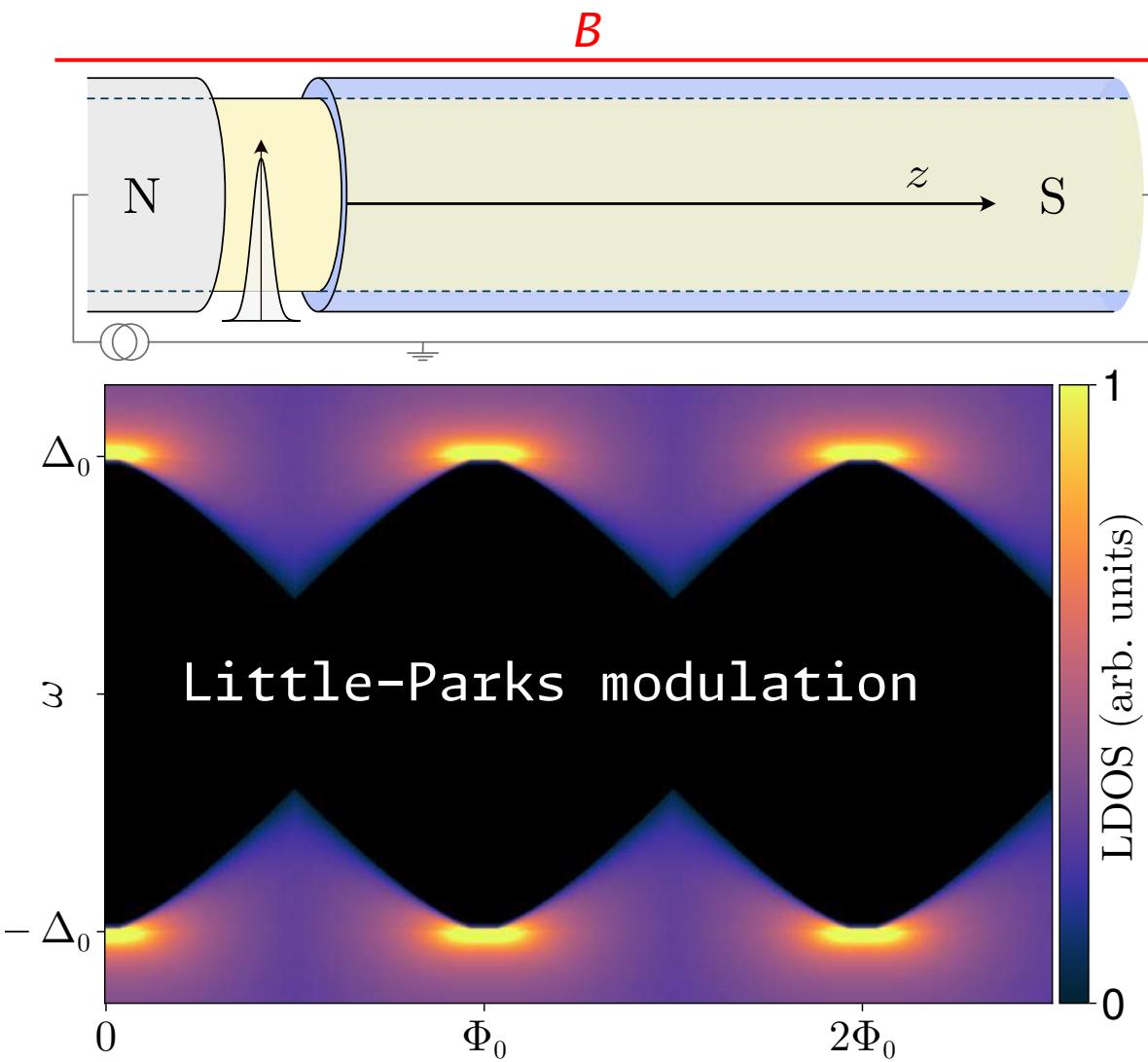
S. Vaitiekėnas et al., Science, 2020



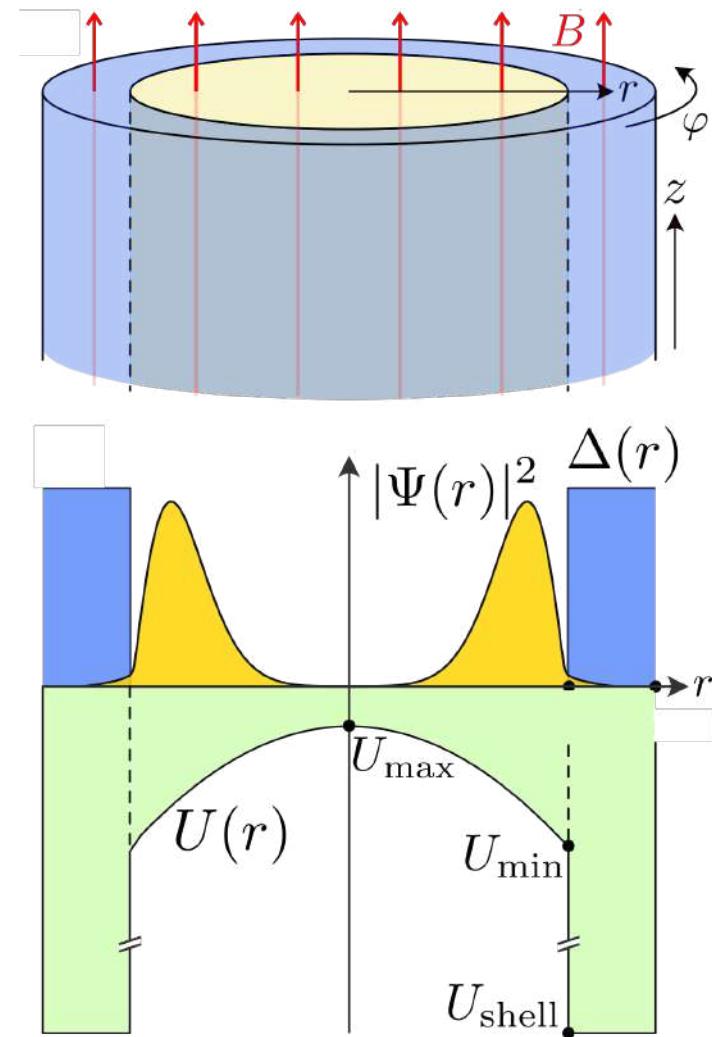
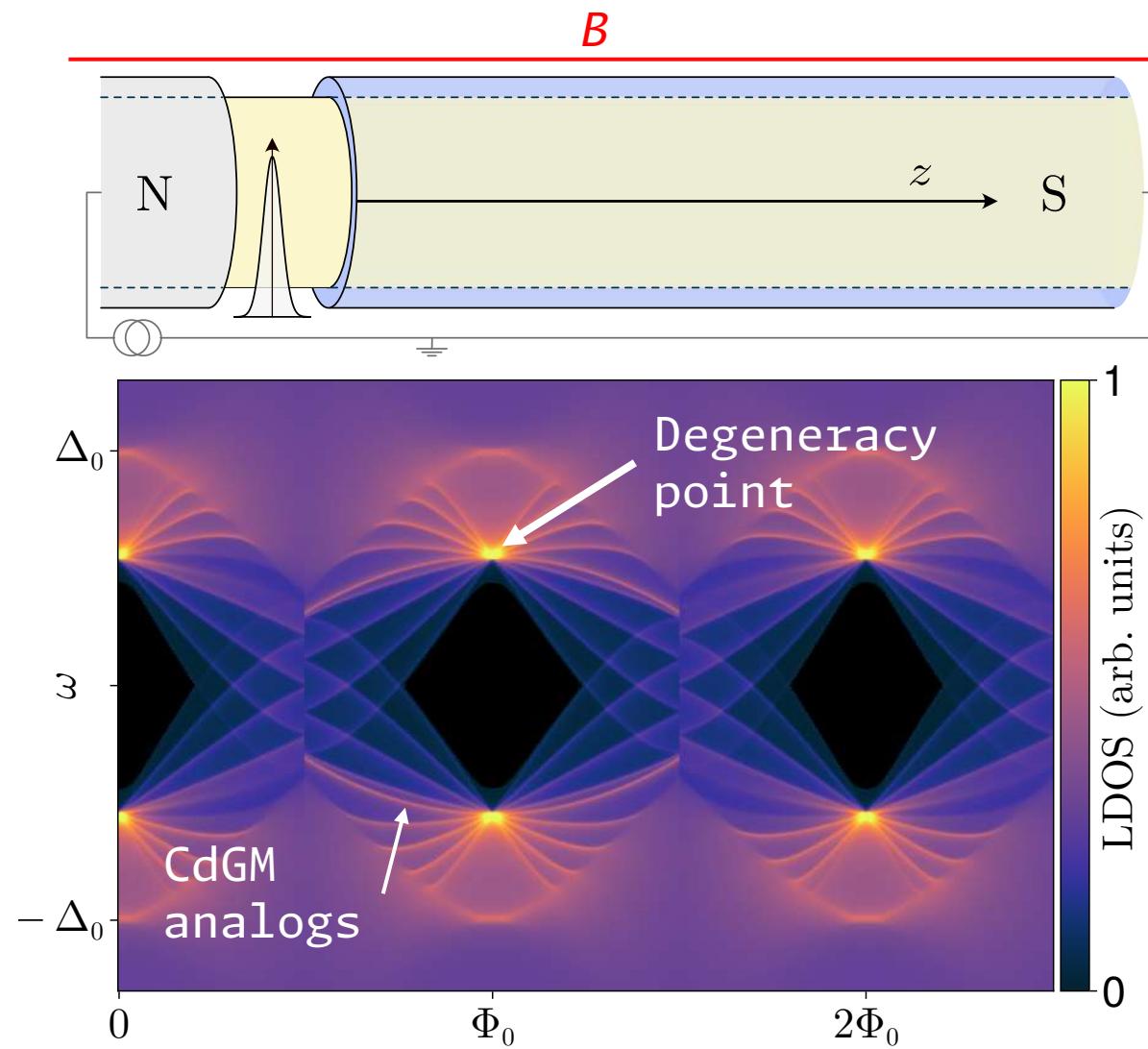
- Topological at lower magnetic fields
- Protected from charge noise

- Cylindrical symmetry
- Charge at interface
- SOC induced by band bending

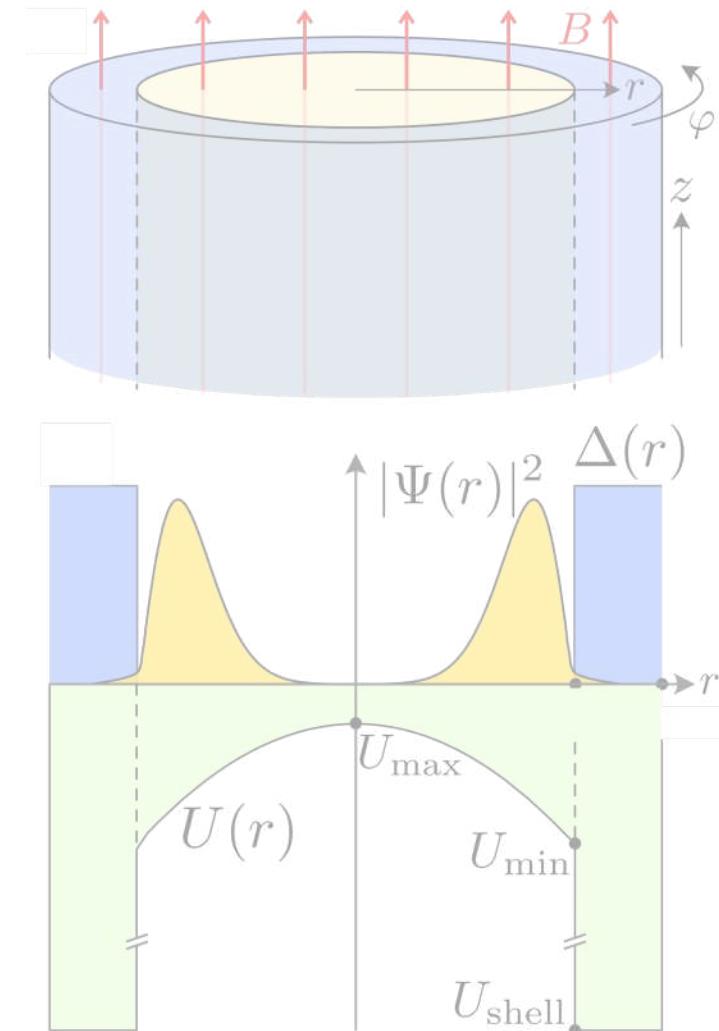
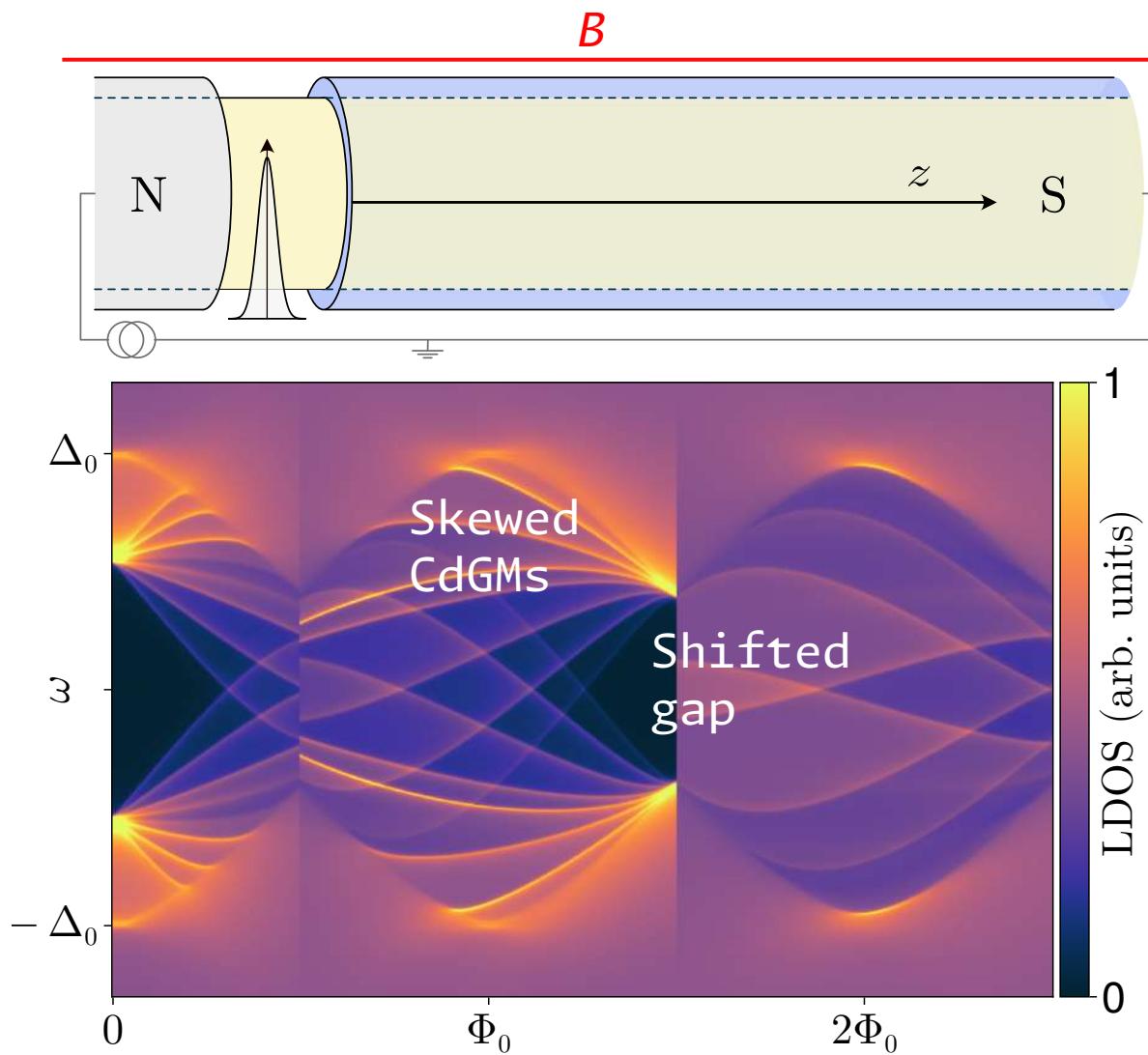
# Sub-gap levels skewness at the edge



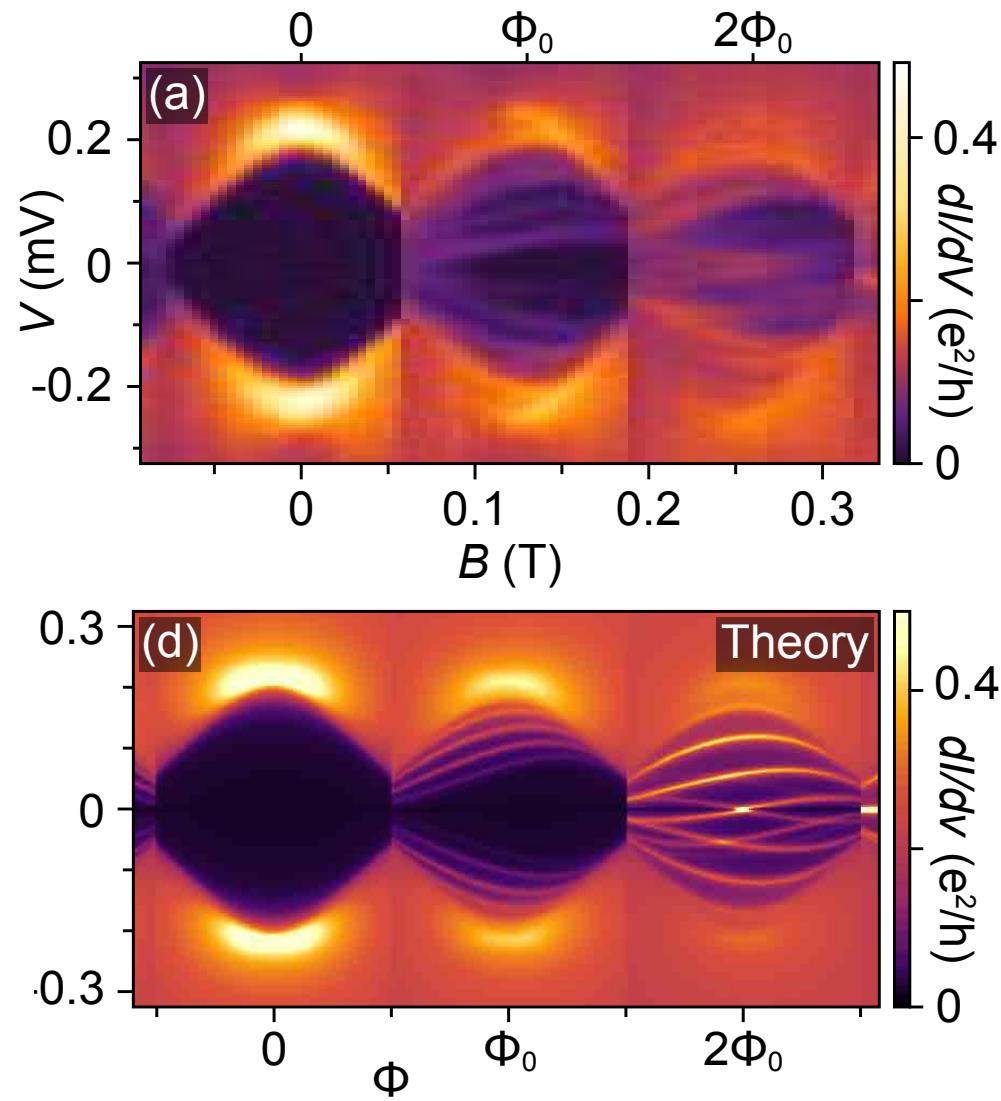
# Sub-gap levels skewness at the edge



# Sub-gap levels skewness at the edge

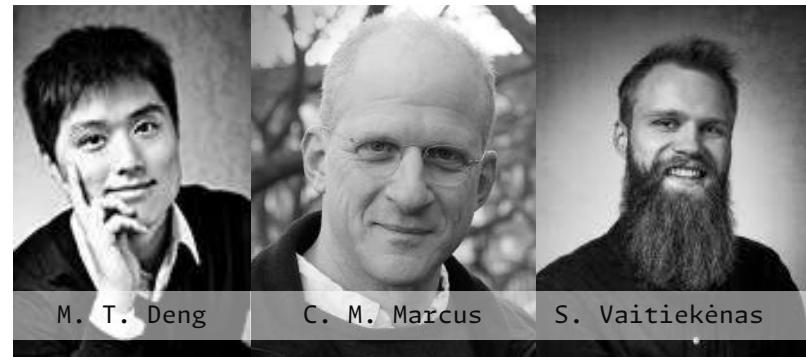


# CdGMs experimental demonstration



*Caroli-de Gennes-Matricon analogs in full-shell hybrid nanowires*

M. T. Deng, C. Payá, P. San-Jose, E. Prada,  
C. M. Marcus and S. Vaitiekėnas  
arXiv:2501.05419



UNIVERSITY OF  
COPENHAGEN

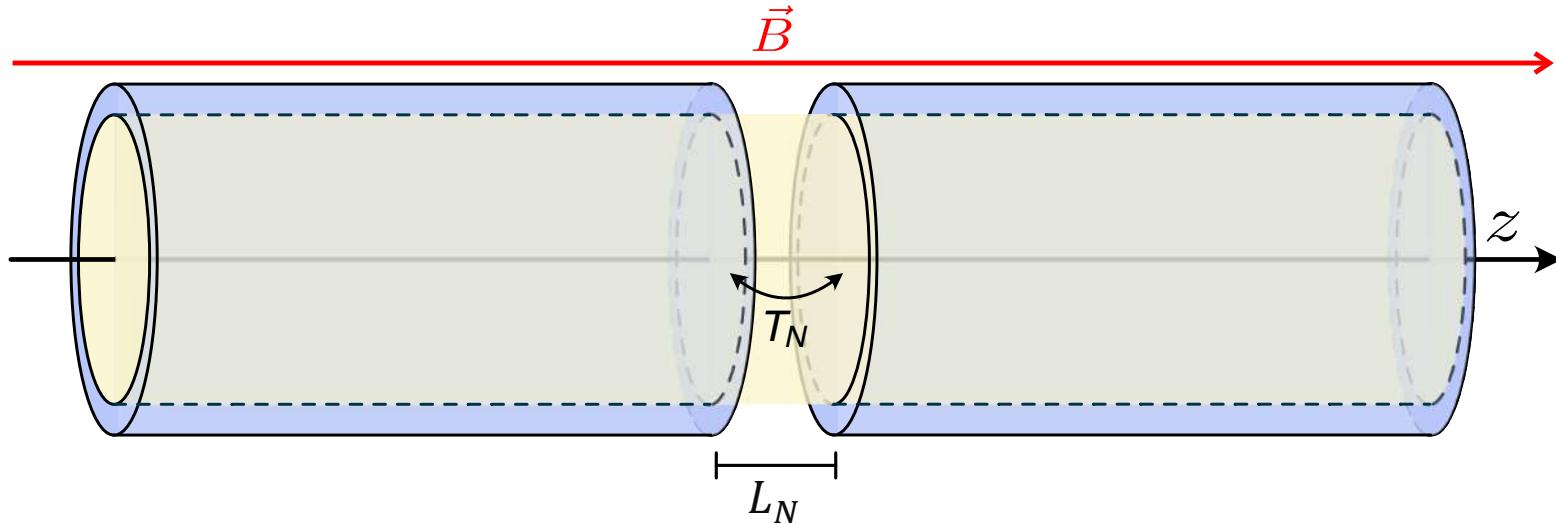
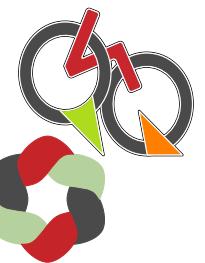




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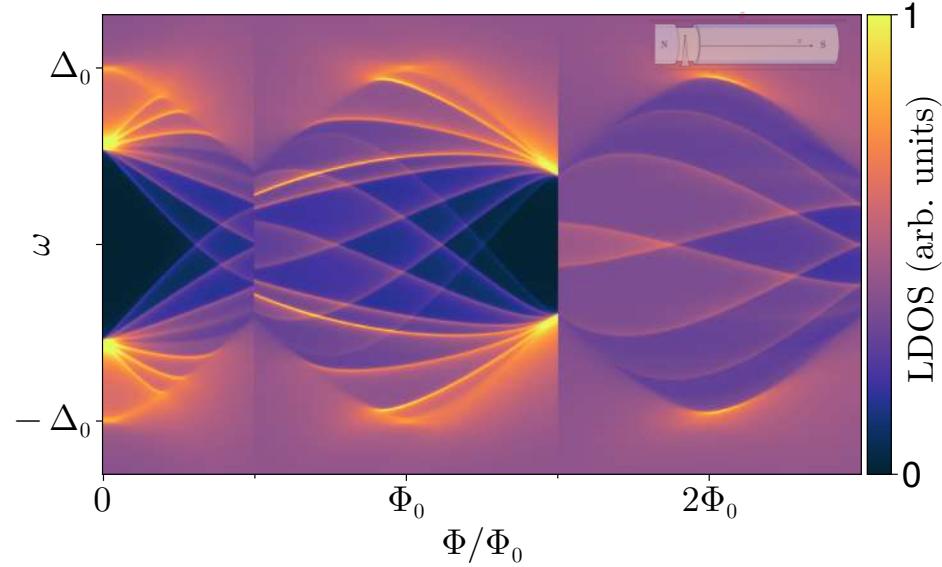
# What do we expect in a Josephson junction?

# A full-shell Josephson junction

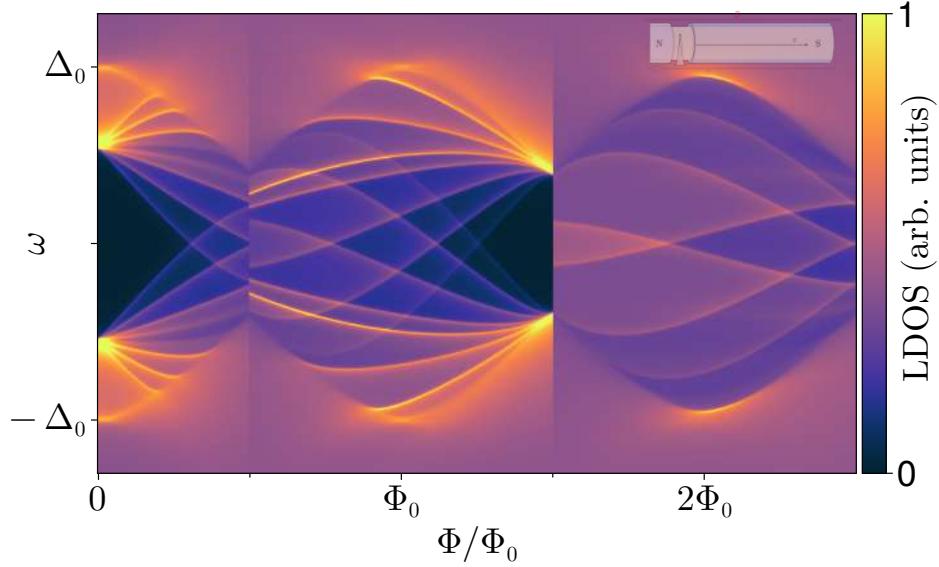


- Equal nanowires
- Short junction,  $L_N \ll \xi_{SC}$
- Controlled transparency  $T_N$
- No voltage bias  $\Rightarrow$  dc Josephson

# Critical current skewness

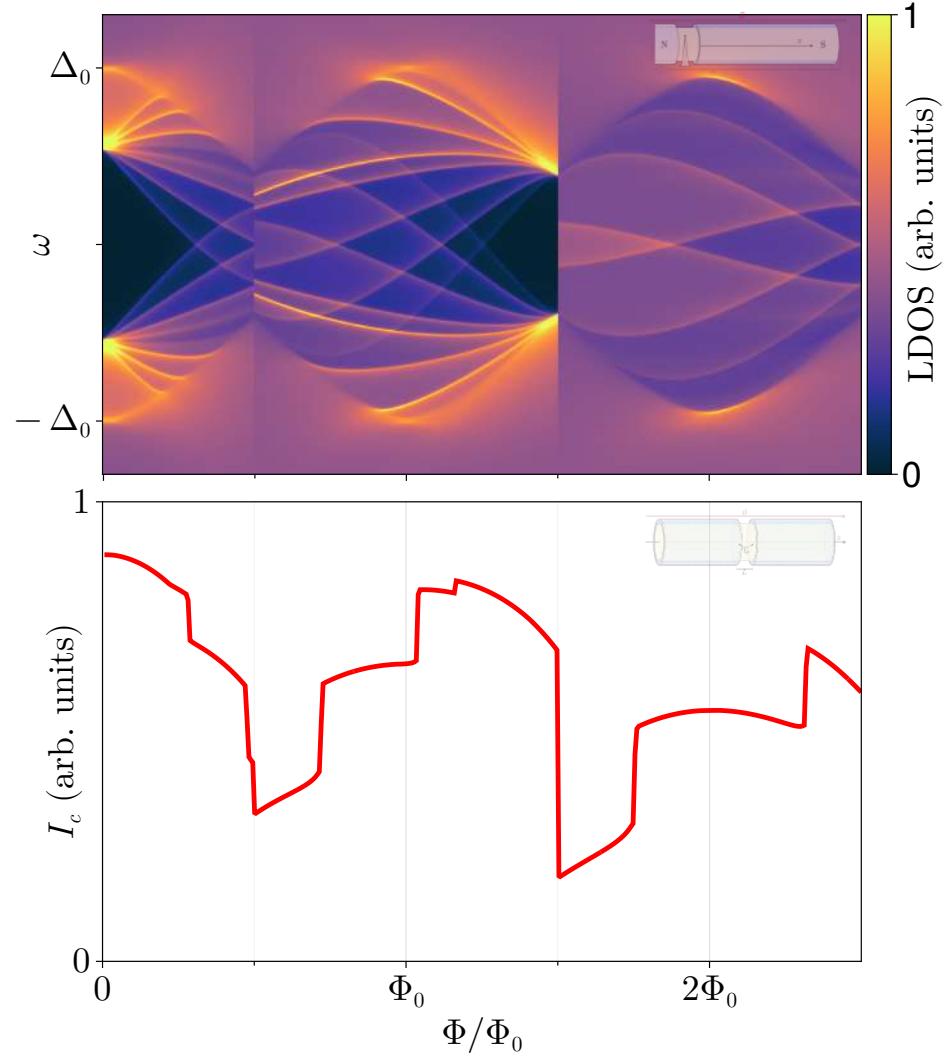


# Critical current skewness



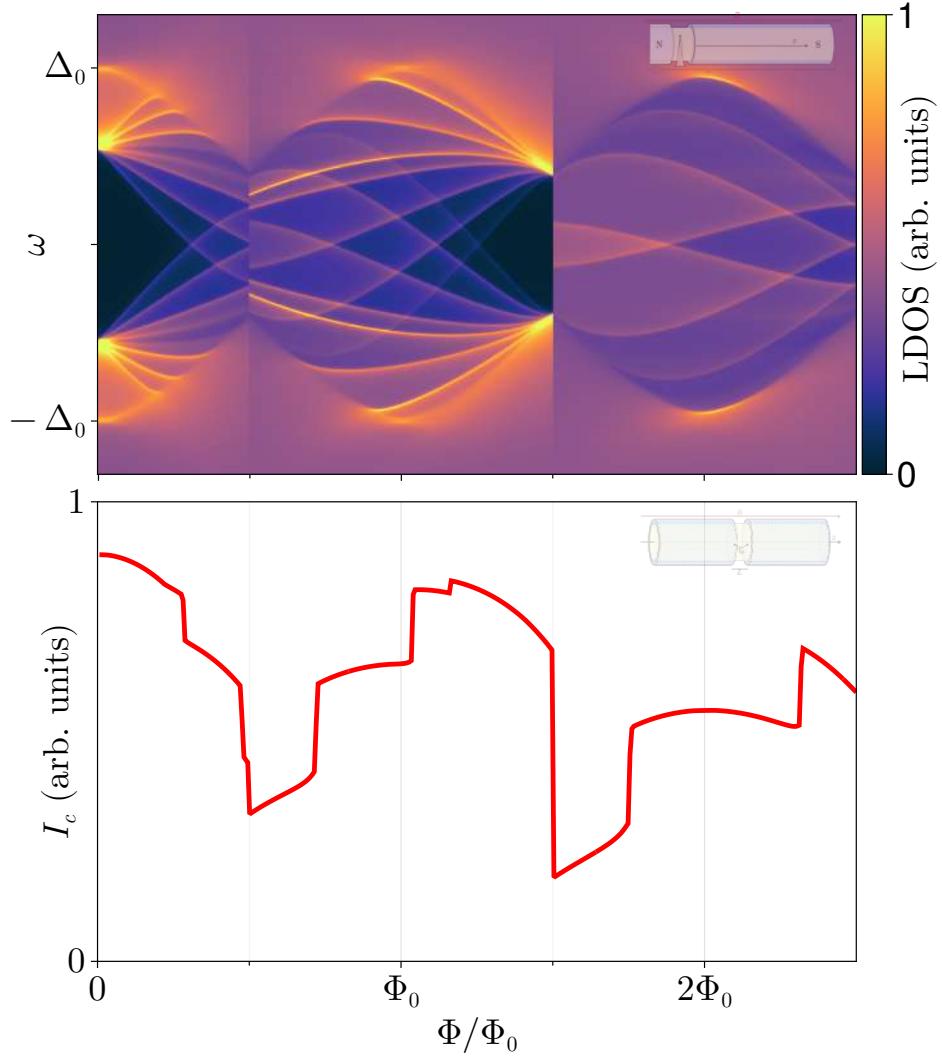
$$J_S(\phi) = \frac{2e}{h} \operatorname{Re} \int d\omega f(\omega) 2\operatorname{Tr}[(\Sigma^r G^r - G^r \Sigma^r) \tau_z]$$
$$I_c = \max_{\phi} \{J_S\}$$

# Critical current skewness



$$J_S(\phi) = \frac{2e}{h} \operatorname{Re} \int d\omega f(\omega) 2\operatorname{Tr}[(\Sigma^r G^r - G^r \Sigma^r) \tau_z]$$
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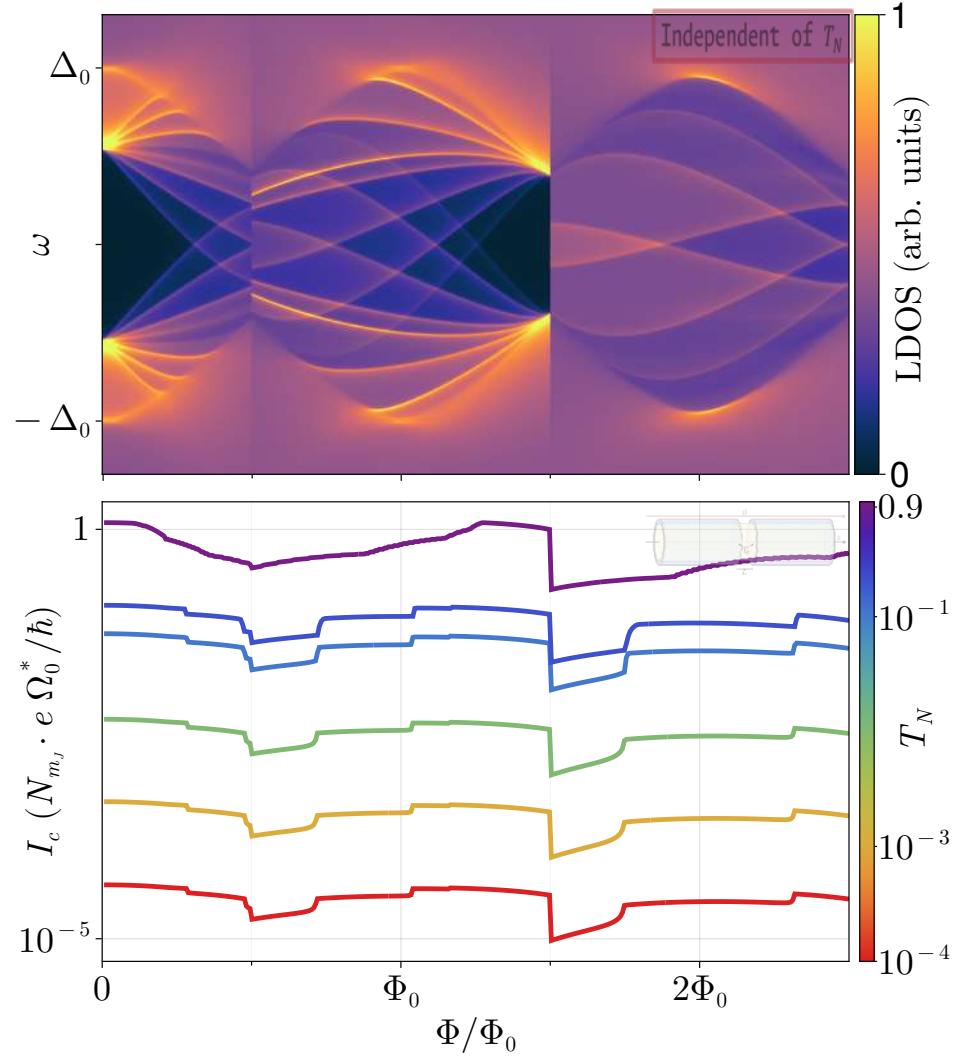
# Critical current skewness



$$J_S(\phi) = \frac{2e}{h} \operatorname{Re} \int d\omega f(\omega) 2\operatorname{Tr}[(\Sigma^r G^r - G^r \Sigma^r) \tau_z]$$
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- Little-Parks modulation
- Skewness to right within LP lobes
- Due to CdGM crossings at 0 energy
- ↔ Current steps

# Critical current skewness

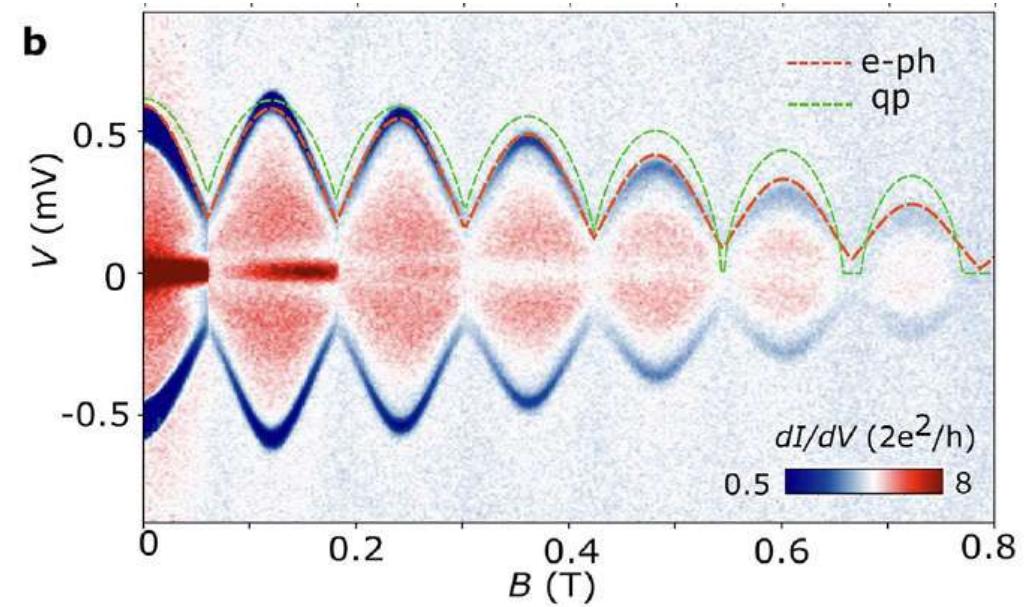
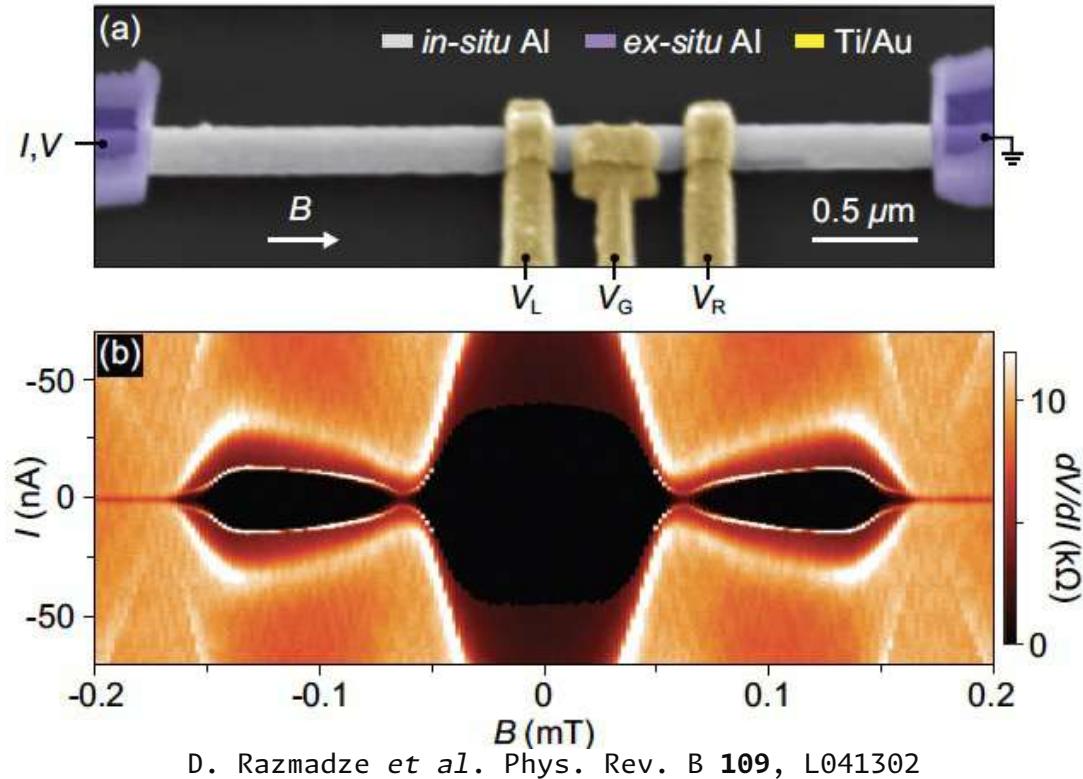
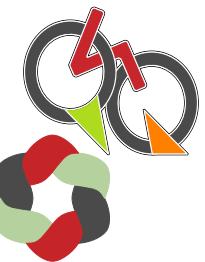


$$J_S(\phi) = \frac{2e}{h} \operatorname{Re} \int d\omega f(\omega) 2\operatorname{Tr}[(\Sigma^r G^r - G^r \Sigma^r) \tau_z]$$
$$I_c = \max_{\phi} \{J_S\}$$

- Little-Parks modulation
- Skewness to right within LP lobes
- Due to CdGM crossings at 0 energy
- ↔ Current steps

Independent of  $T_N$

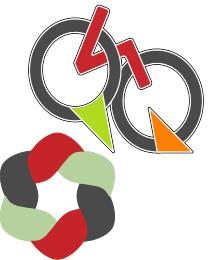
# Skewness experimental signatures



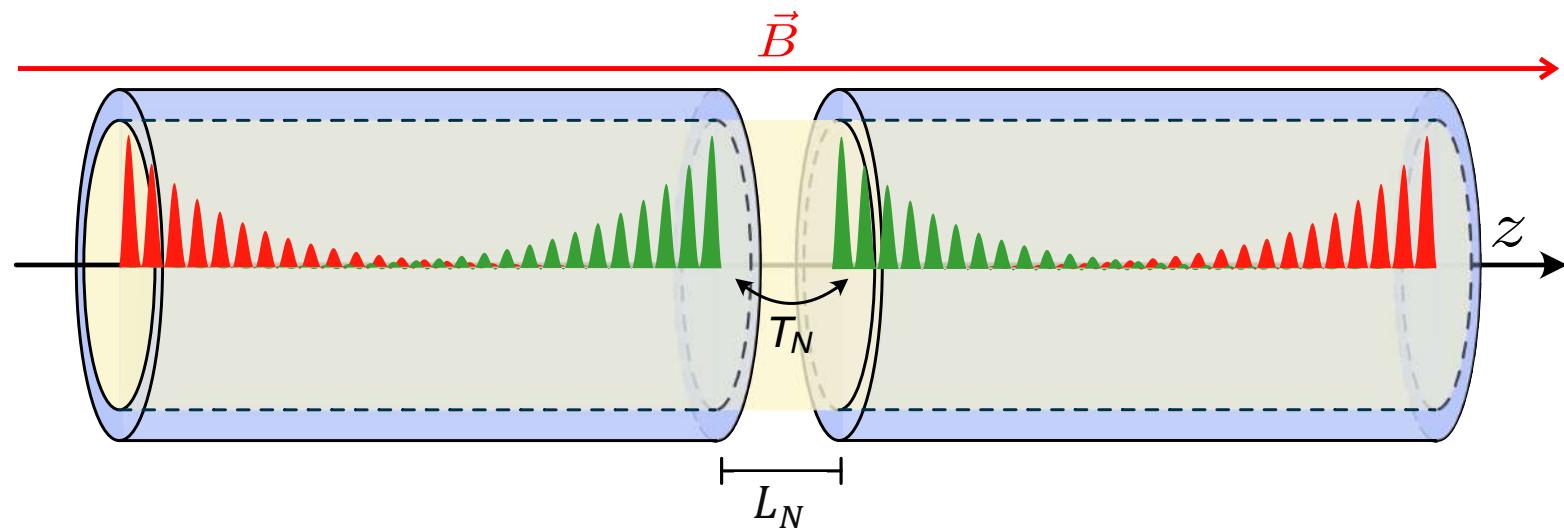
A. Ibabe et al. Nano Lett. 2024, 24, 22, 6488-6495

E. Lee group  
IFIMAC, Madrid

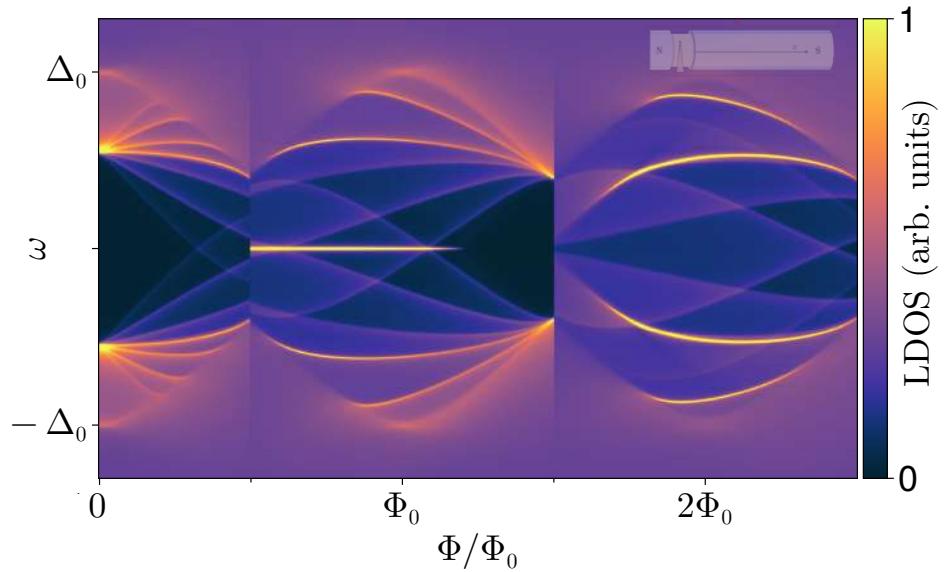
C. M. Marcus and S. Vaitiekėnas group  
NBI, Copenhagen



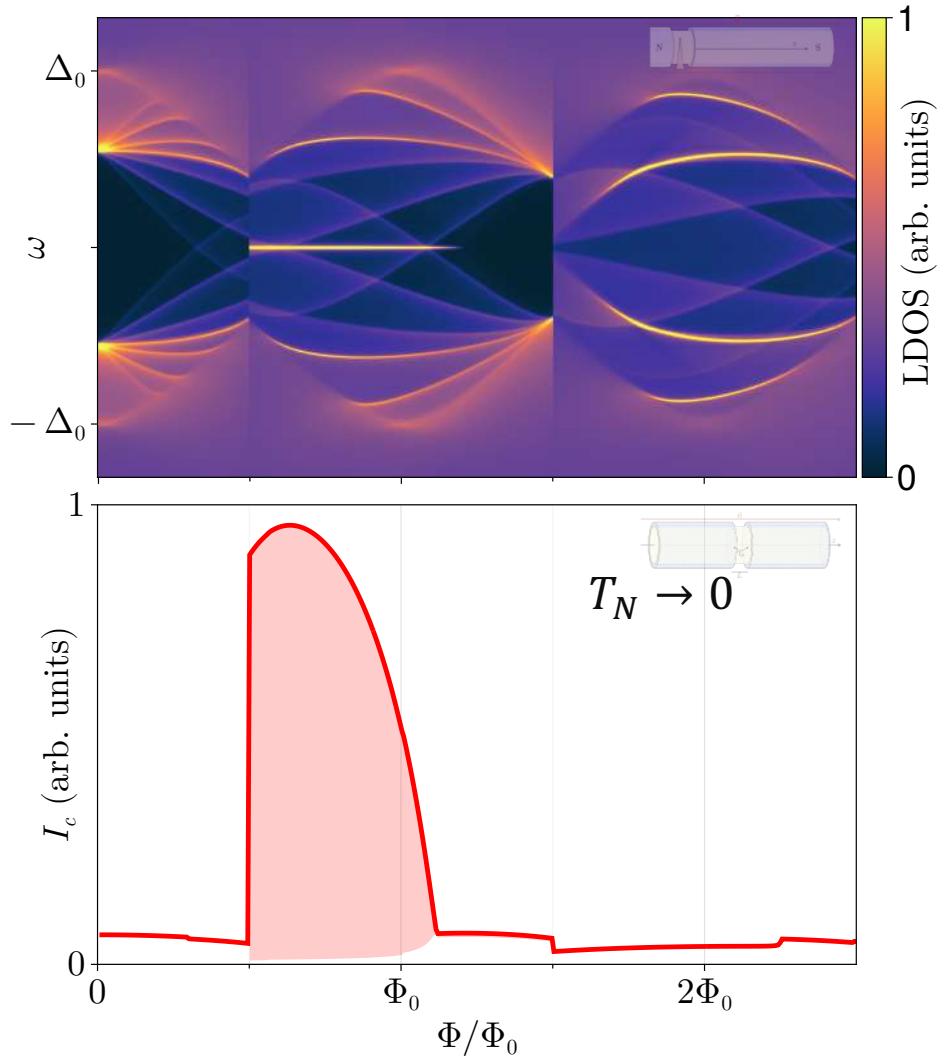
# What if there are Majoranas?



# Majorana critical current fin



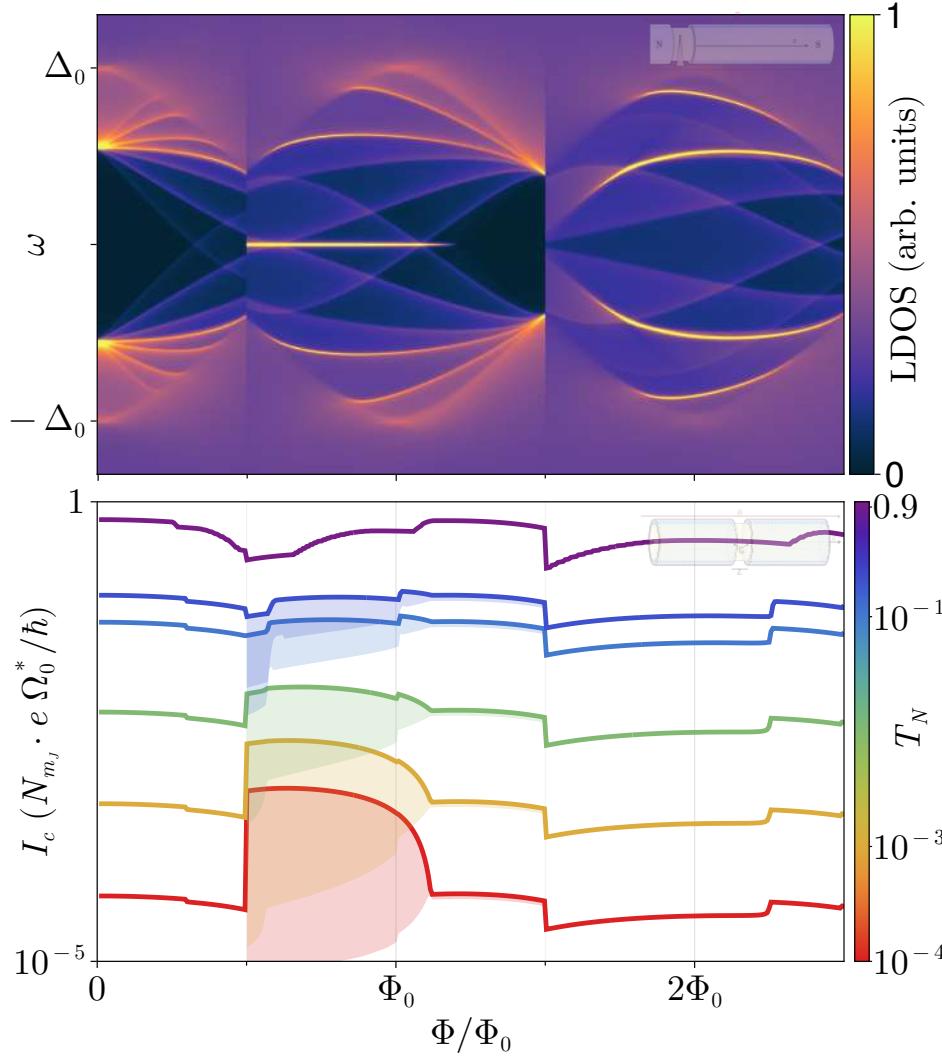
# Majorana critical current fin



Majorana  $\longleftrightarrow$  Current fin

CdGMs  $\longleftrightarrow$  Skewness to right

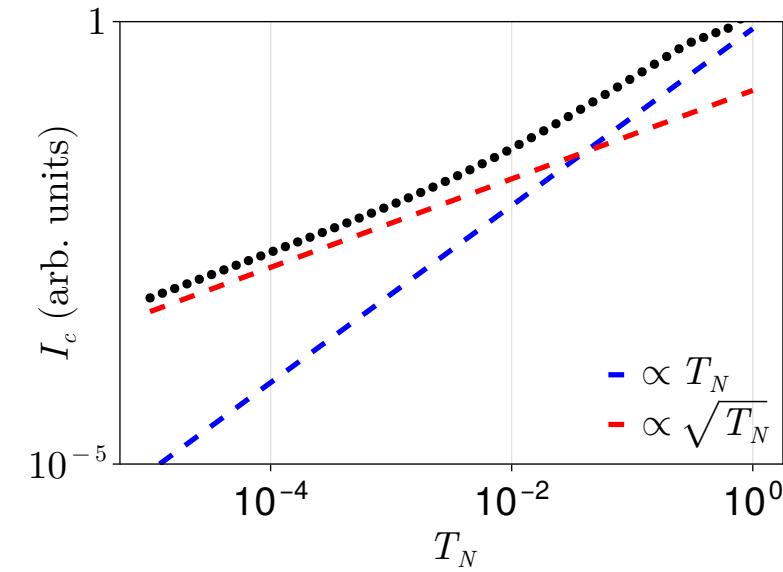
# Majorana critical current fin



Majorana  $\xrightarrow{\text{↔}}$  Current fin

CdGMs  $\xrightarrow{\text{↔}}$  Skewness to right

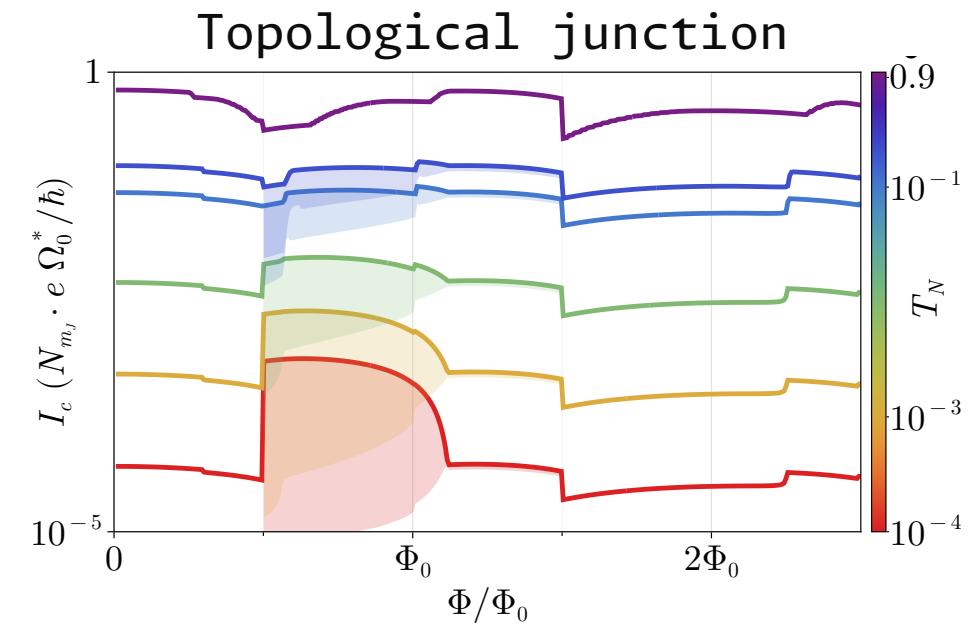
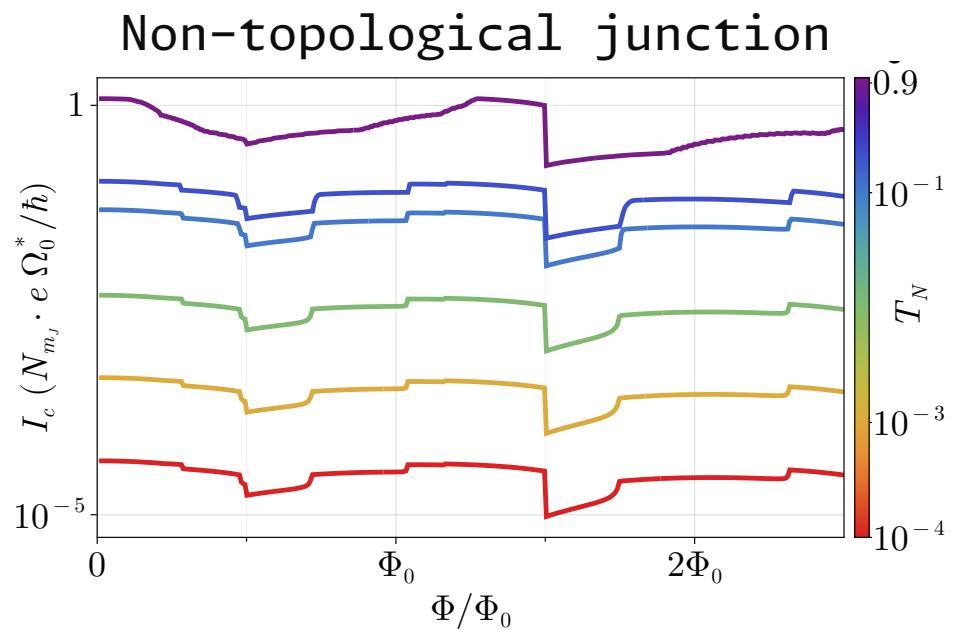
Crossover in transparency

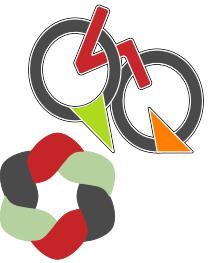


# Conclusions



- Full-shell nanowires host **non-topological subgap states** ➔ CdGMs
- CdGMs **skew** Josephson critical current towards **higher fluxes** within all Little-Parks lobes for **all transparencies**
- Majoranas give the Josephson critical current a **fin shape** within odd Little-Parks lobes for **low transparencies**





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**Full story just appeared on arXiv!!**

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# Josephson effect in full-shell hybrid nanowires

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PID2021-125343NB-I00  
PRE2022-101362

