Superconducting Triplet *Rim Currents* in a Spin-Textured Ferromagnetic Disk

Correlated States and Dynamics in Quantum Materials workshop

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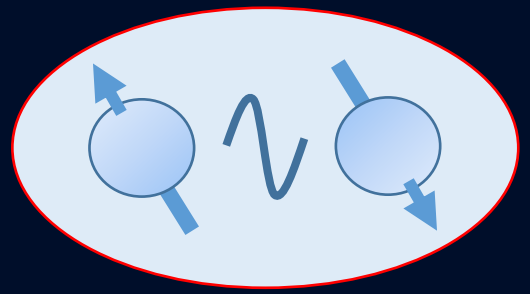
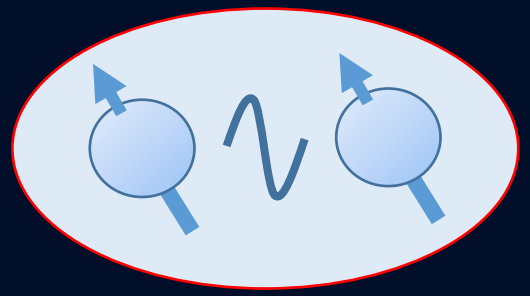
15-05-2024

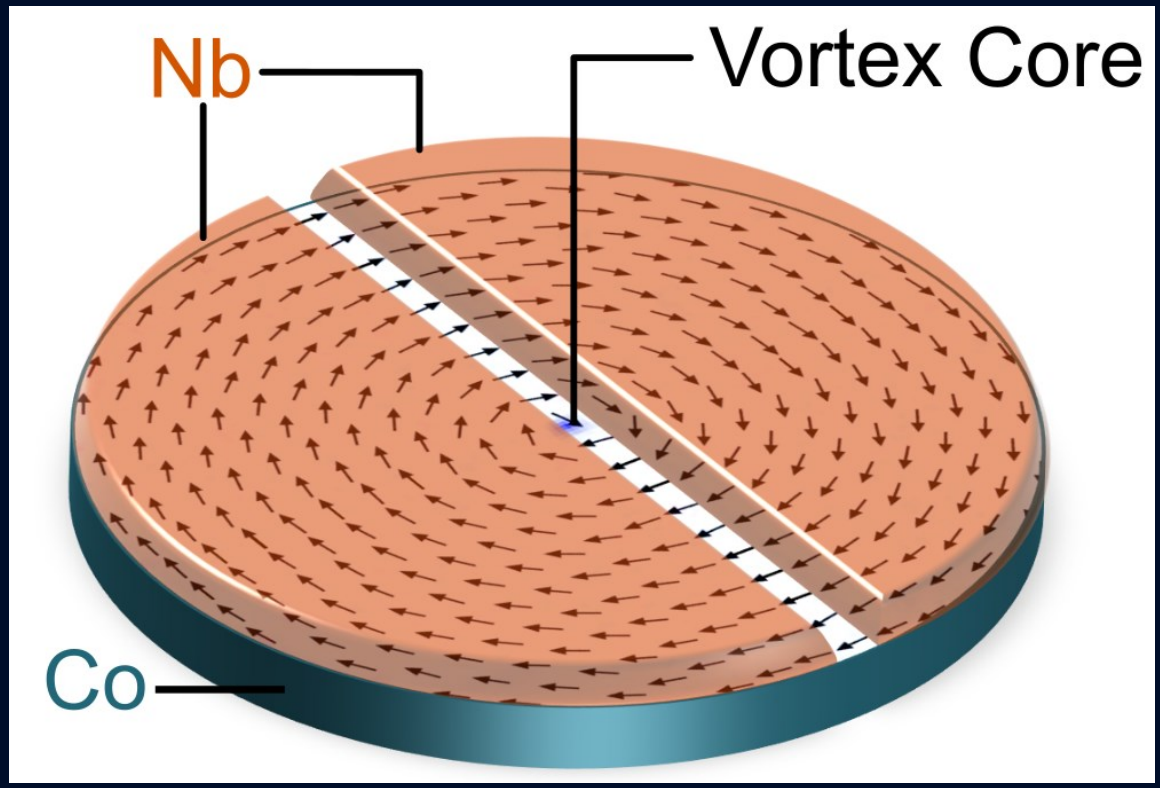
Superconducting proximity in a ferromagnet



Singlet Cooper pair



Triplet Cooper pair



Leiden Institute of Physics

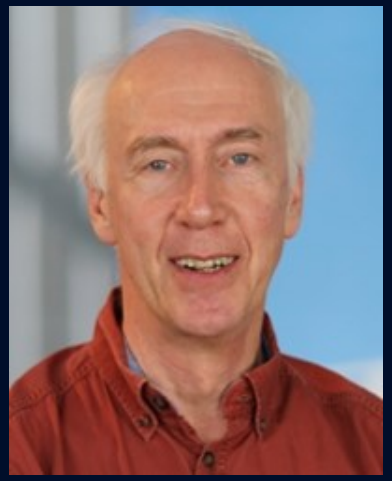
Michiel Hubert

Bart Woltjes

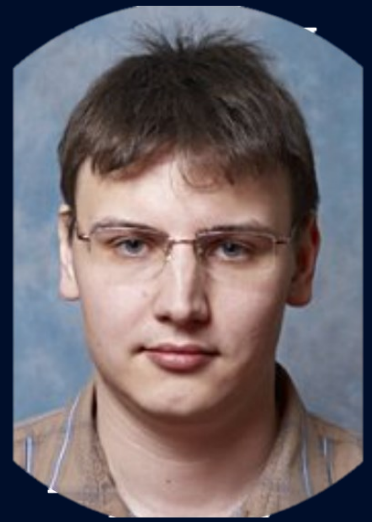
Naor Scheinowitz

Dyon van Dinter

University of Jyväskylä, Finland



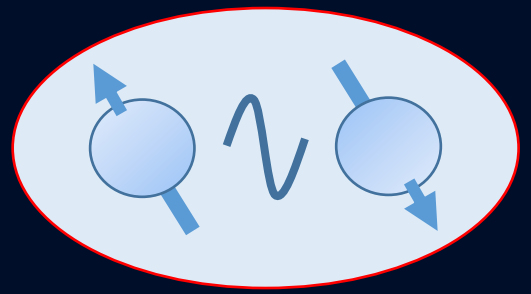
Jan Aarts



Mikhail Silaev

Kaveh Lahabi

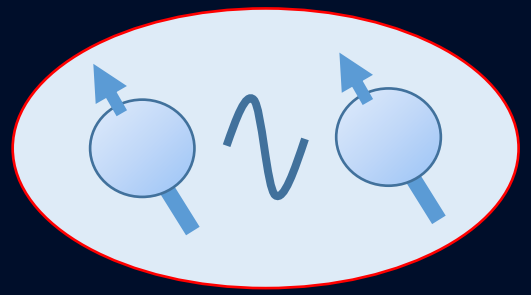
What are triplets?



S = 0

$$\frac{1}{\sqrt{2}}\left(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle\right)$$

Singlet



S = 1

$$\frac{1}{\sqrt{2}}\left(|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle\right)$$

$m_s = 0$

SRT

$$|\uparrow\uparrow\rangle$$

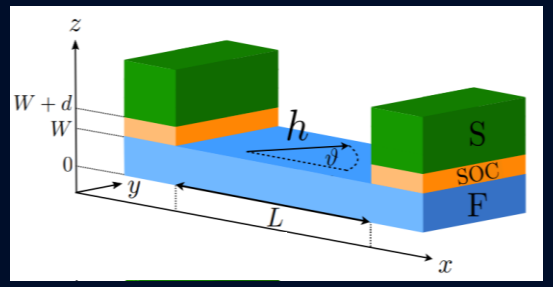
$m_s = 1$

LRT

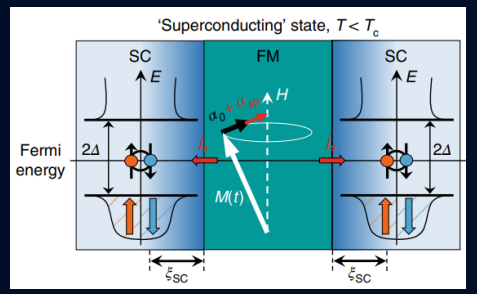
$$|\downarrow\downarrow\rangle$$

$m_s = -1$

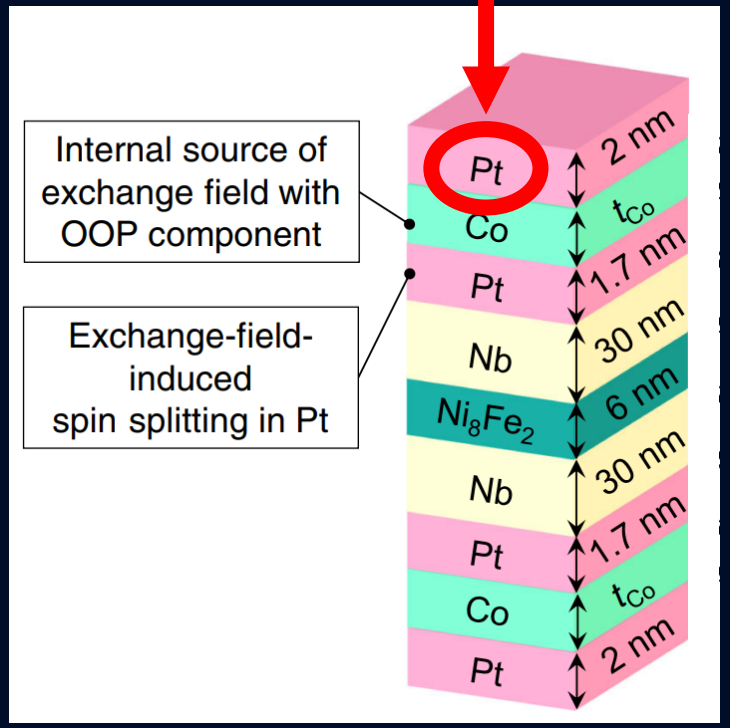
Classic triplet generation



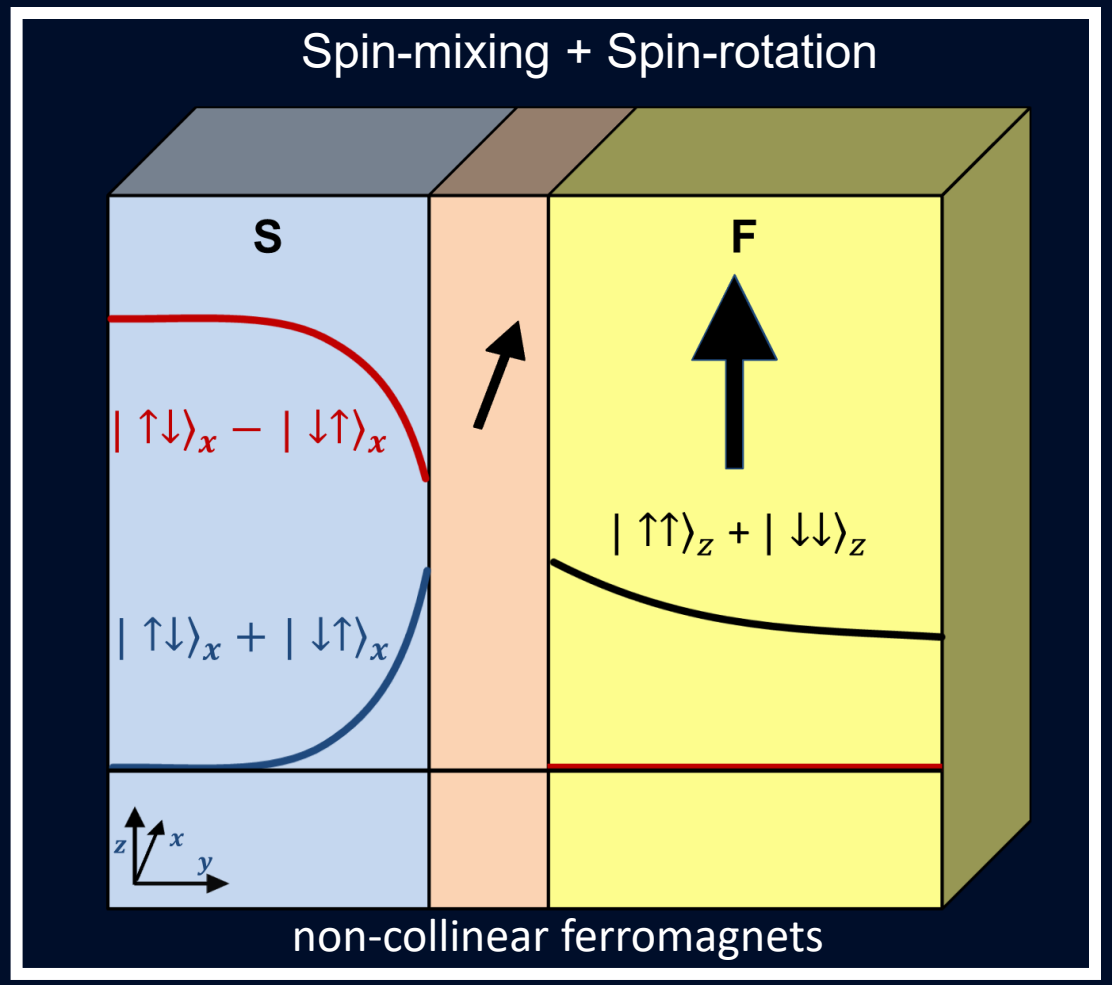
Bujnowski *et al.* PRB **100**, 224518 (2019)



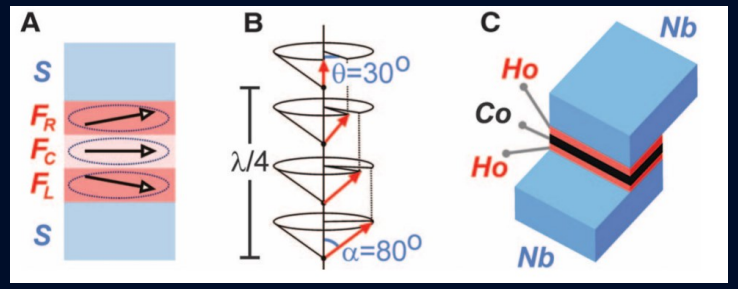
Jeon *et al.* Nat. Mater. **8**, 499–503 (2017)



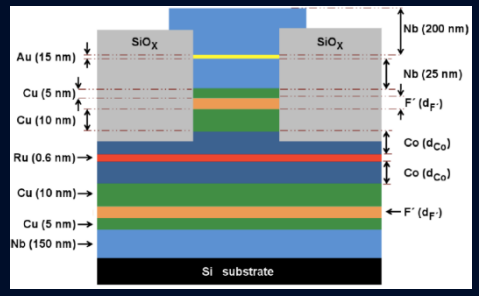
Jeon *et al.* PRX. **10**, 031020 (2020)



spin-orbit coupling

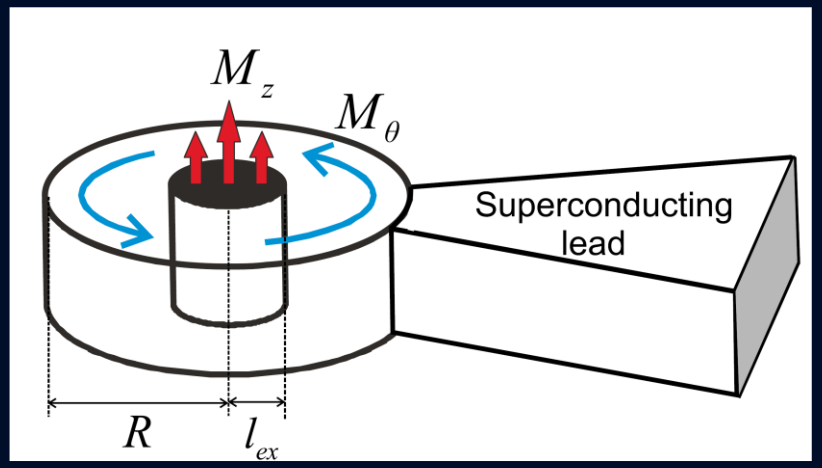


Robinson *et al.* Science, **329**, 59-61 (2010)

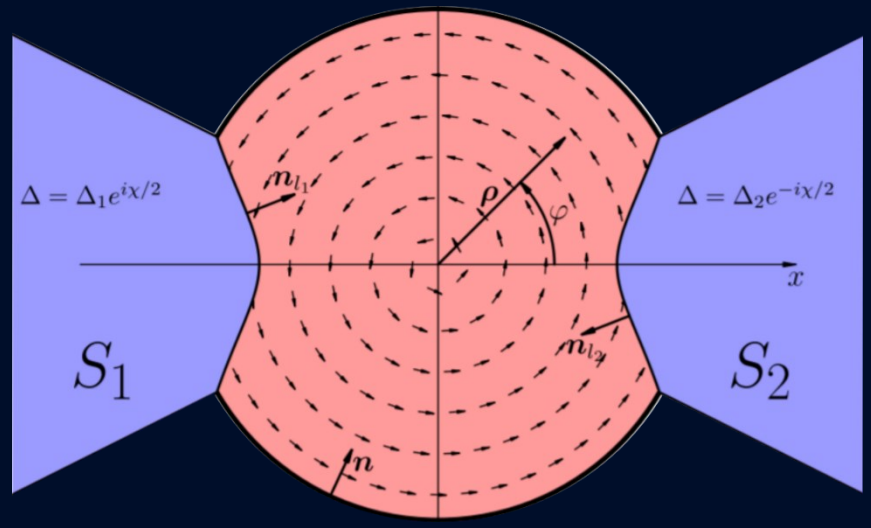


Khaire *et al.* PRL **104**, 137002 (2010)

Alternative triplet generation: spin texture



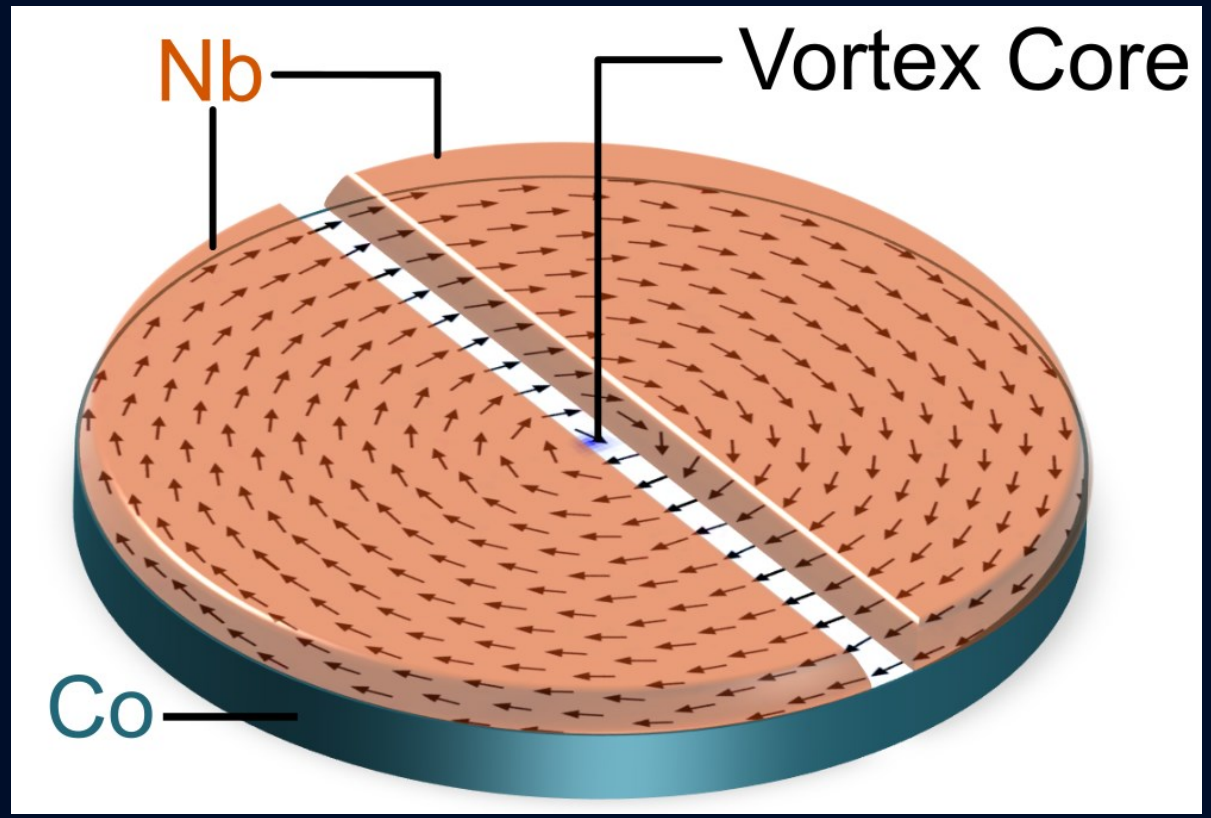
Silaev, PRB **79,** 184505 (2009)

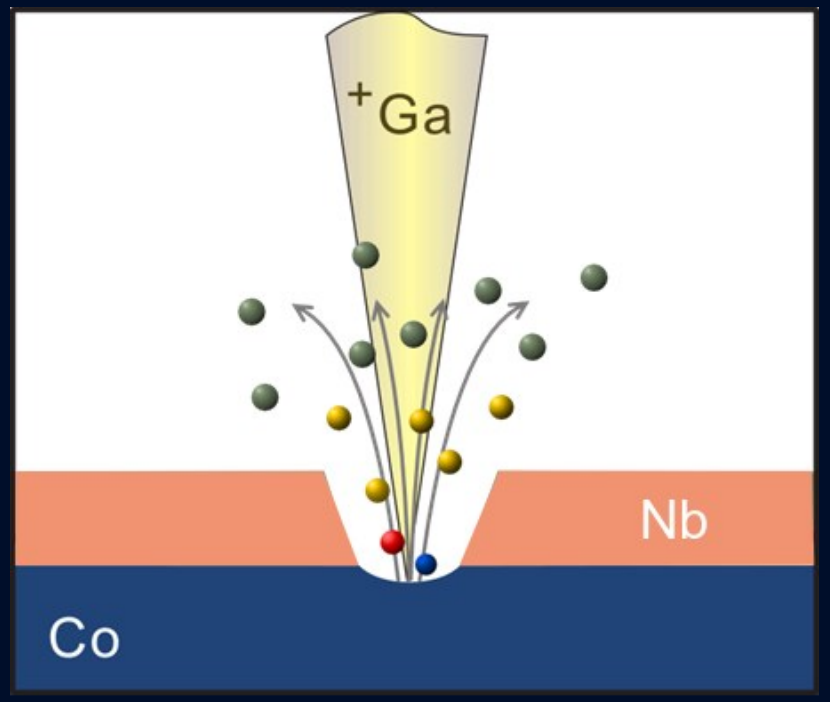


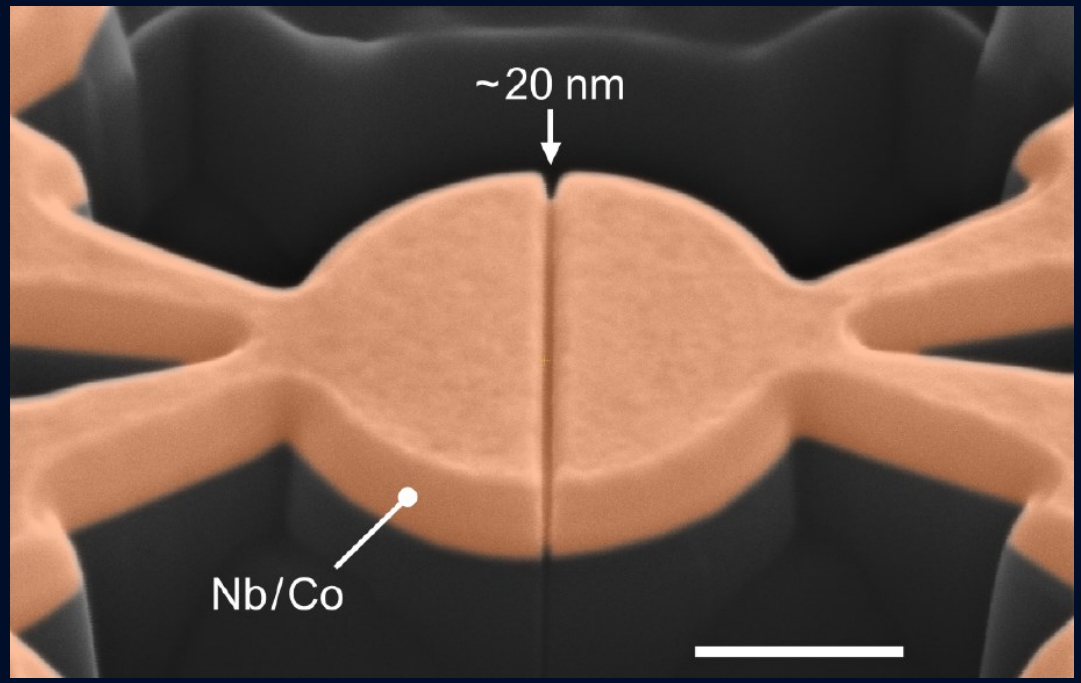
Kalenkov *et al.*, PRL **107**, 087003 (2011)

Not explored experimentally

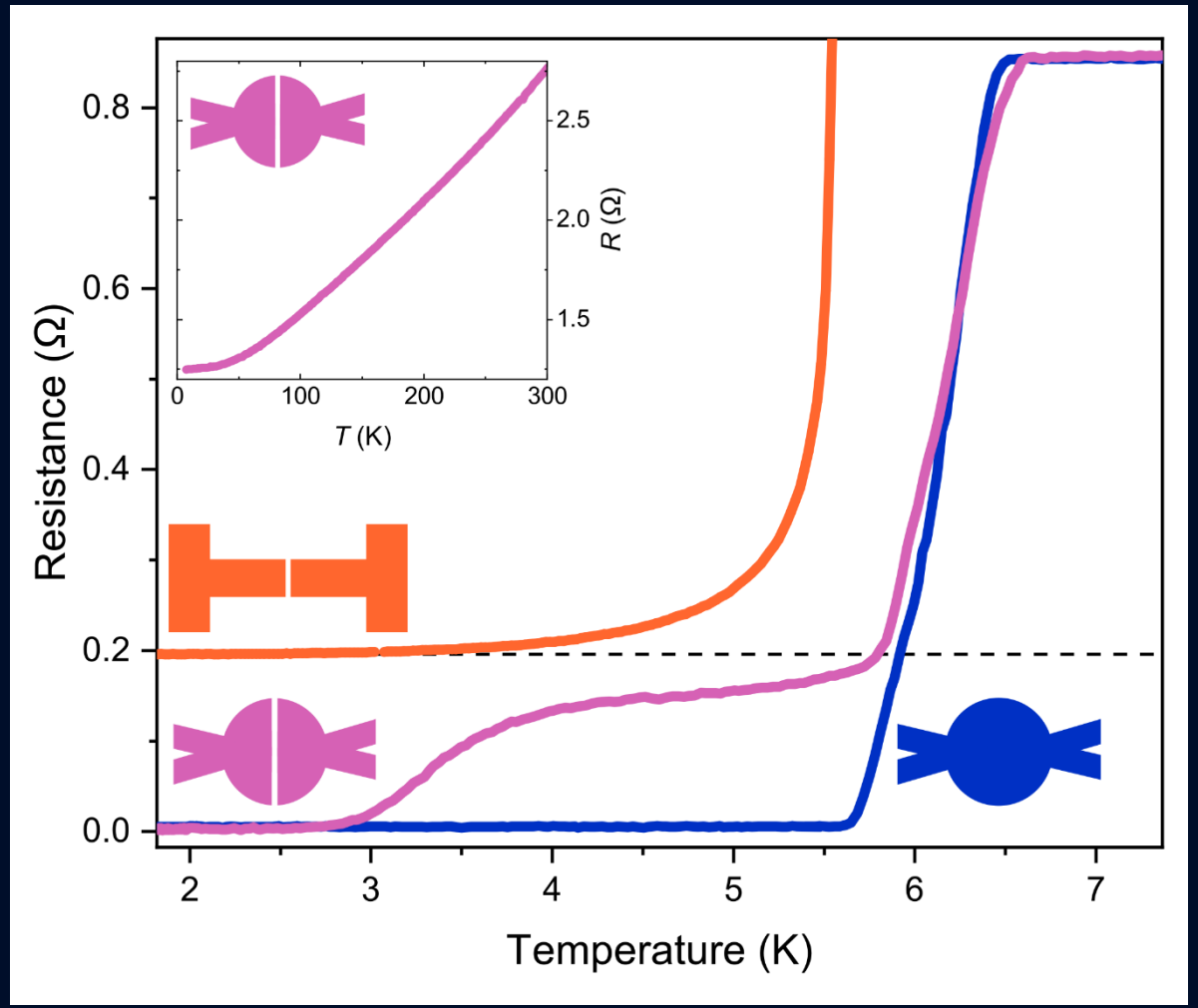
Our approach: disk devices

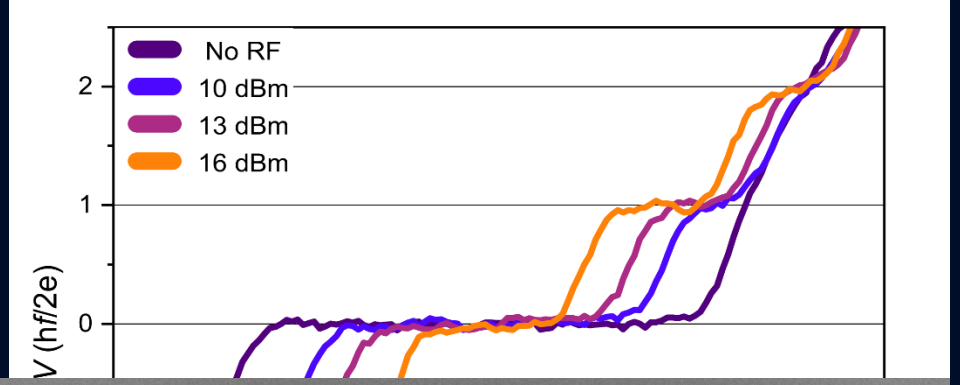


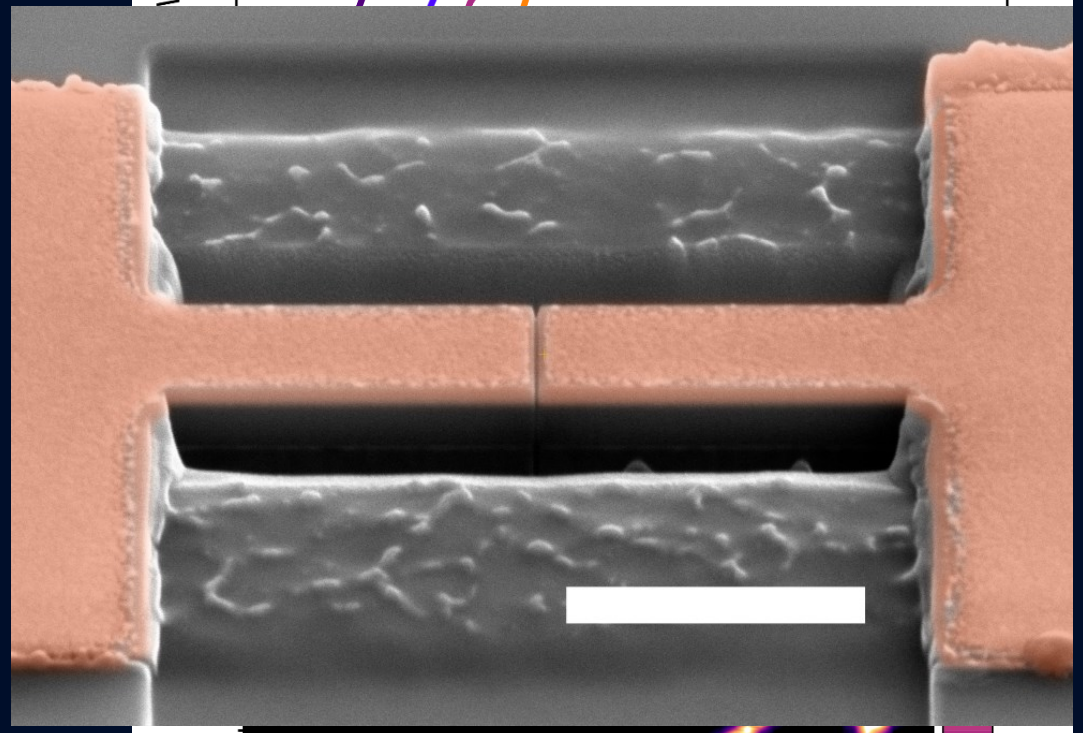


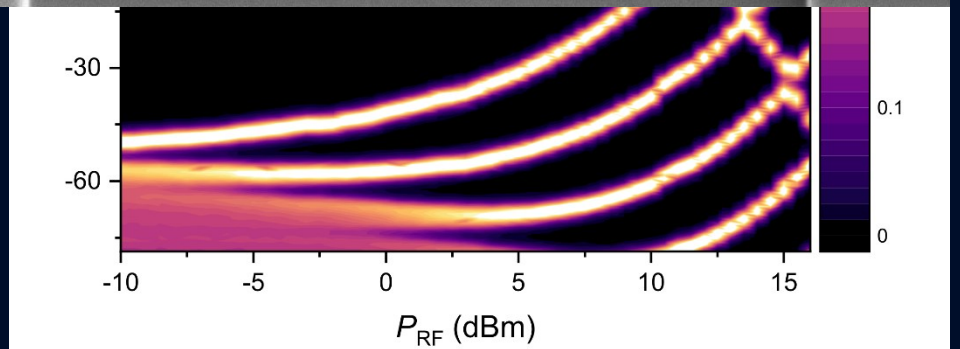


Junction behavior





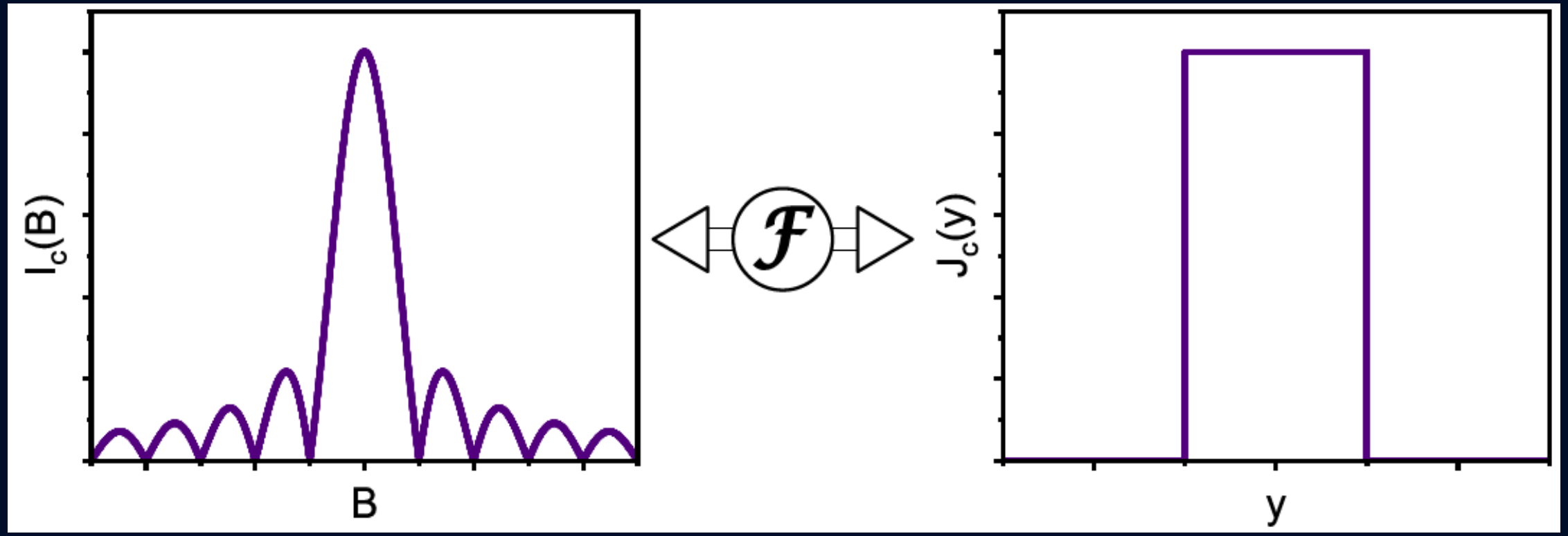




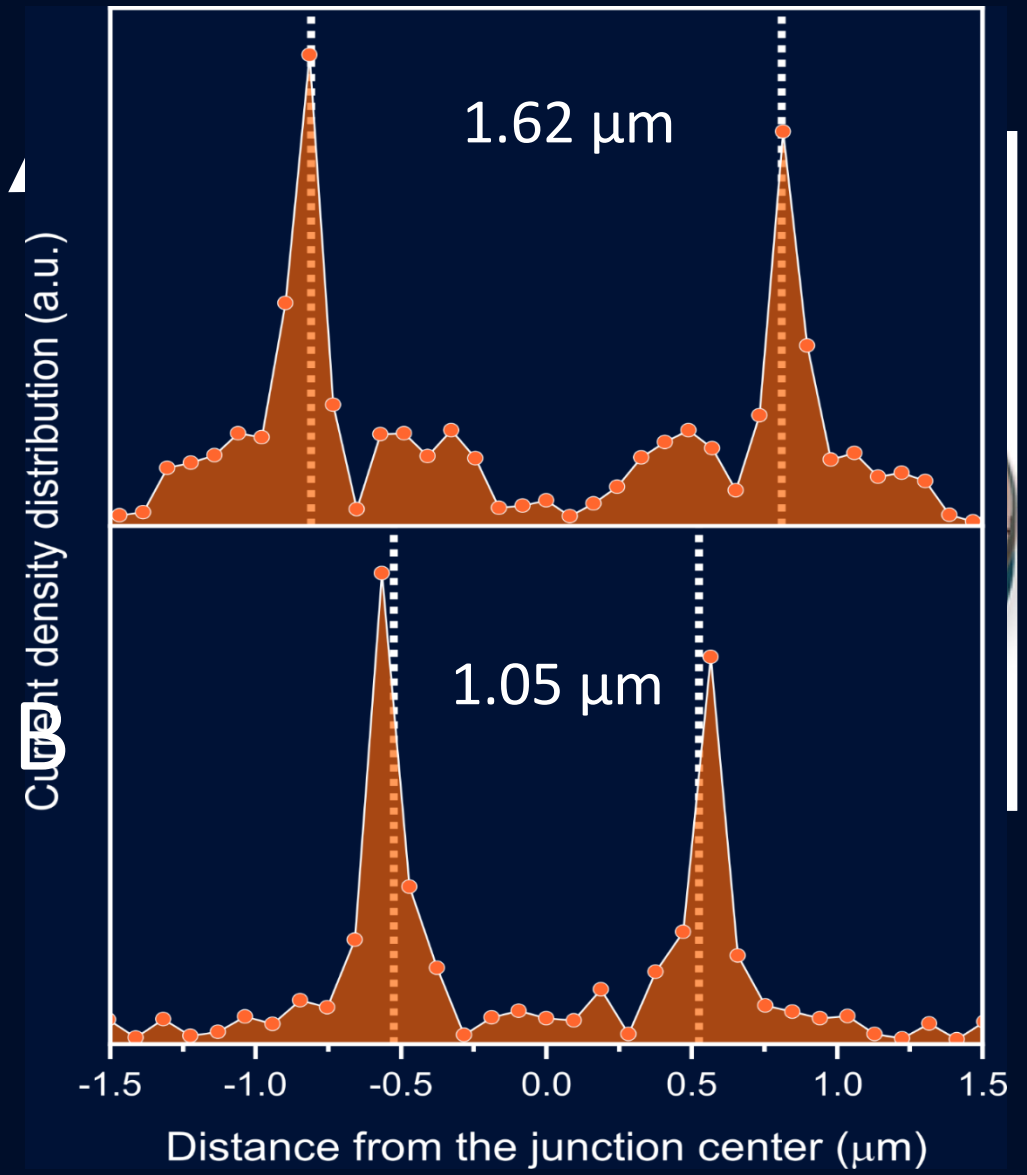
How is the supercurrent distributed?

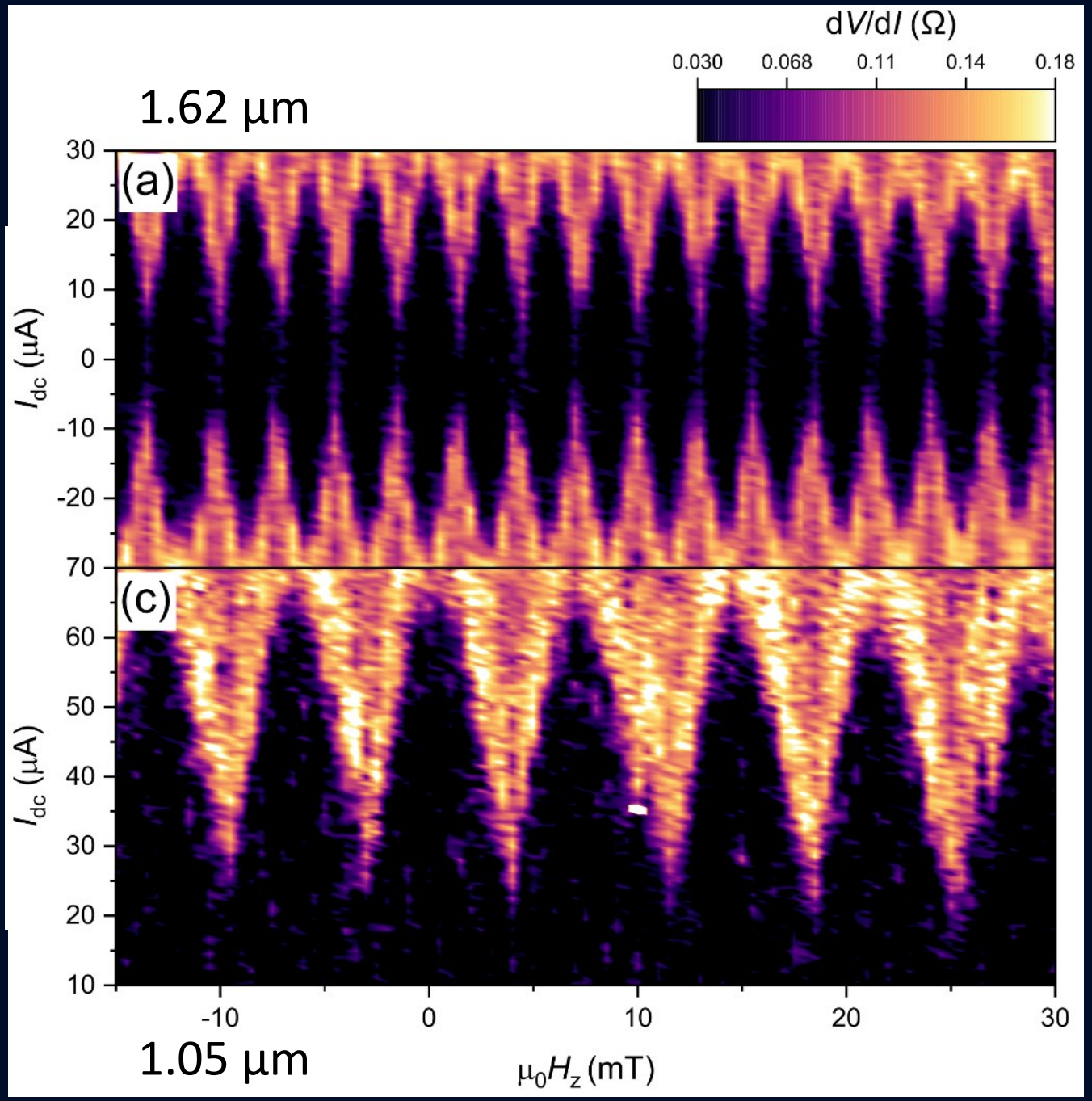
- Analogous to single slit interference pattern
- Measure $I_c(B)$ → extract $J_c(y)$

Based on: Dynes and Fulton PRB **3**, 3015 (1971)



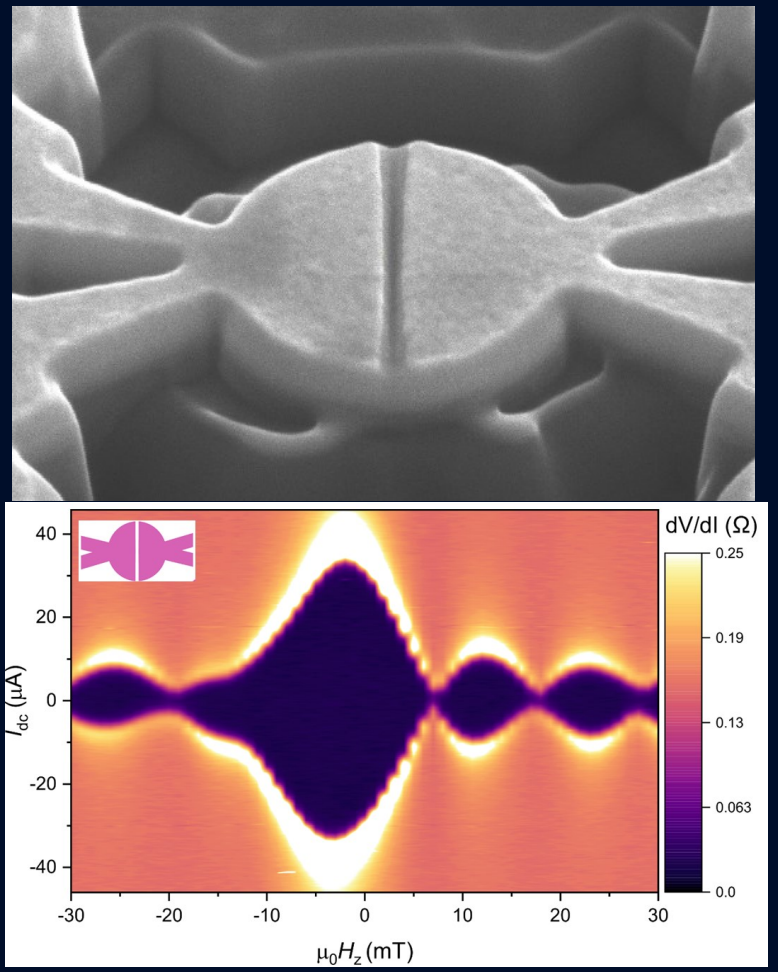
Rim currents



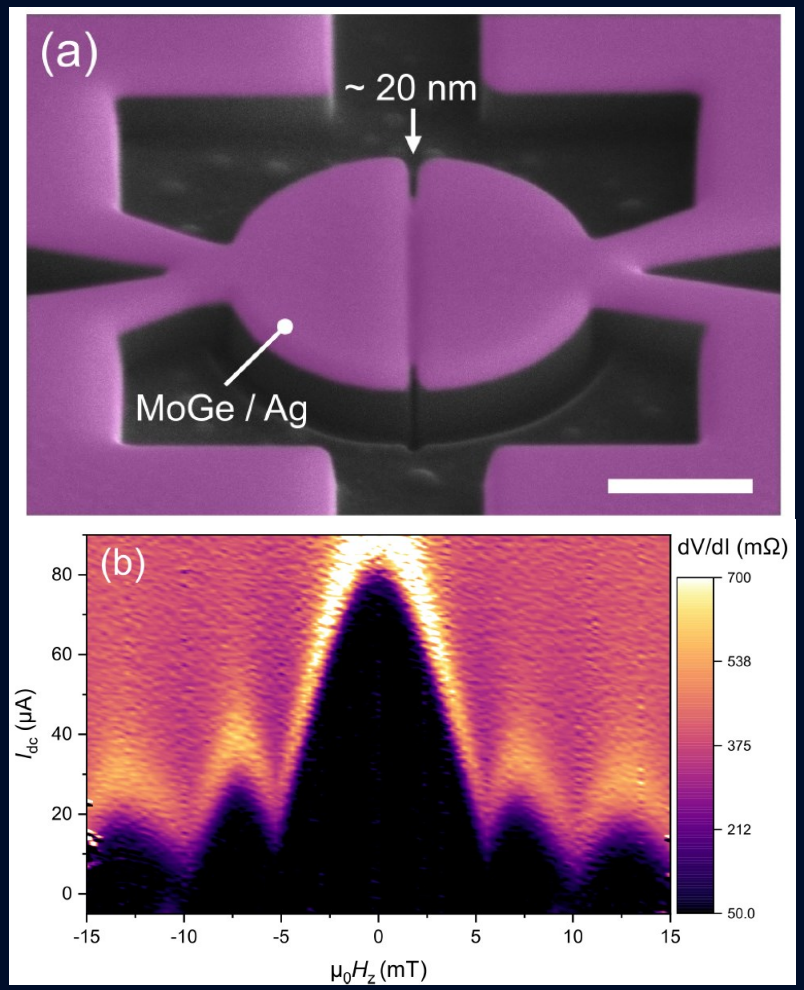


Control experiments

Shallow trench



Non-magnetic junctions

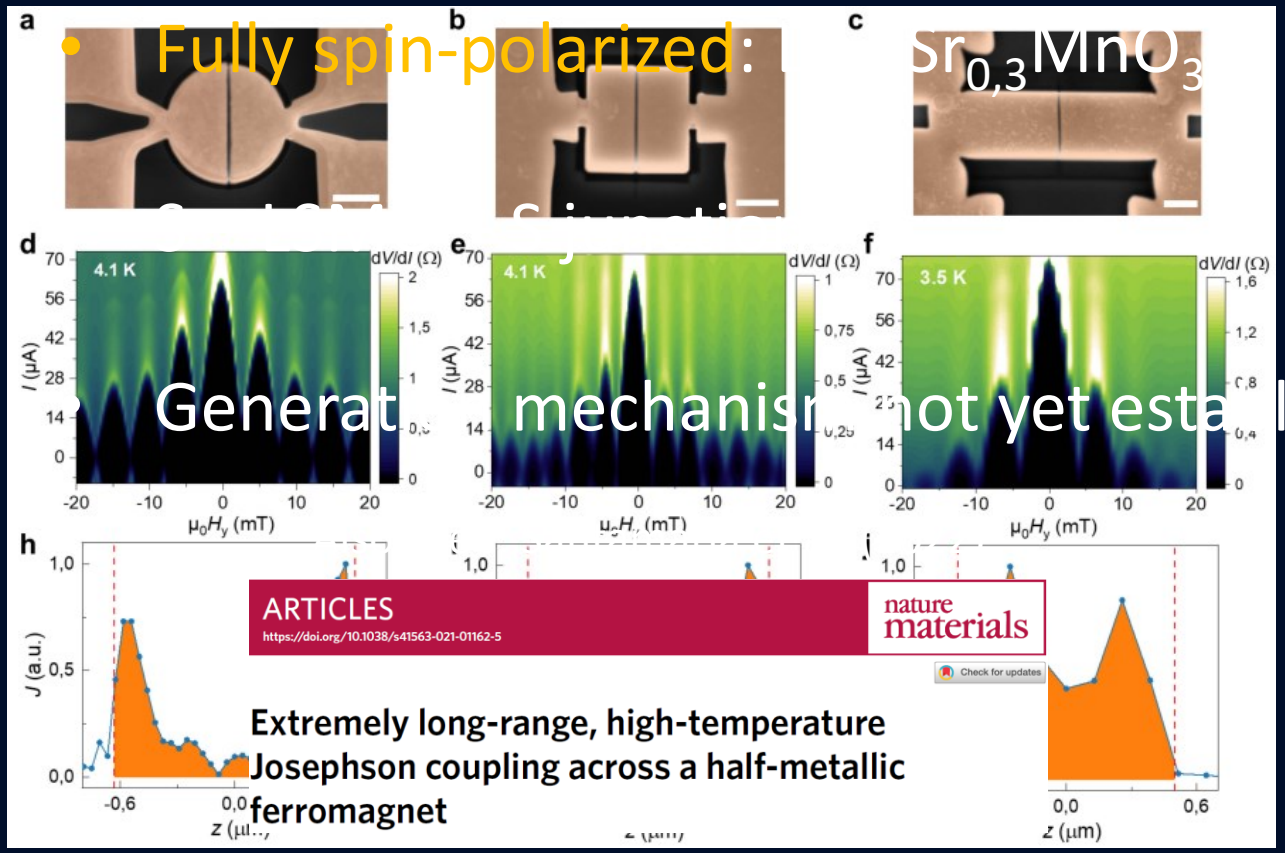


No triplet current

→ No *Rim currents*

LSMO-based *half-metallic* junctions

- Fully spin-polarized: $La_{0,7}Sr_{0,3}MnO_3$
- Generation mechanism not yet established



ARTICLES
https://doi.org/10.1038/s41563-021-01162-5
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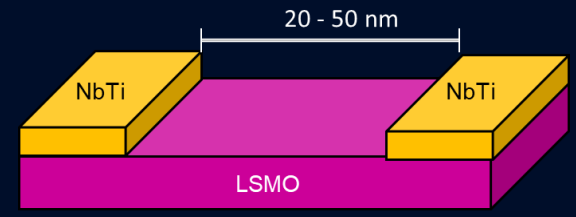
Extremely long-range, high-temperature Josephson coupling across a half-metallic ferromagnet



Rim currents only occur:

1. In a disk geometry
2. When long-range triplets are present.

They are not related to band structure (unlike regular edge currents)

Junxiang Yao

arXiv > cond-mat > arXiv:2303.13922

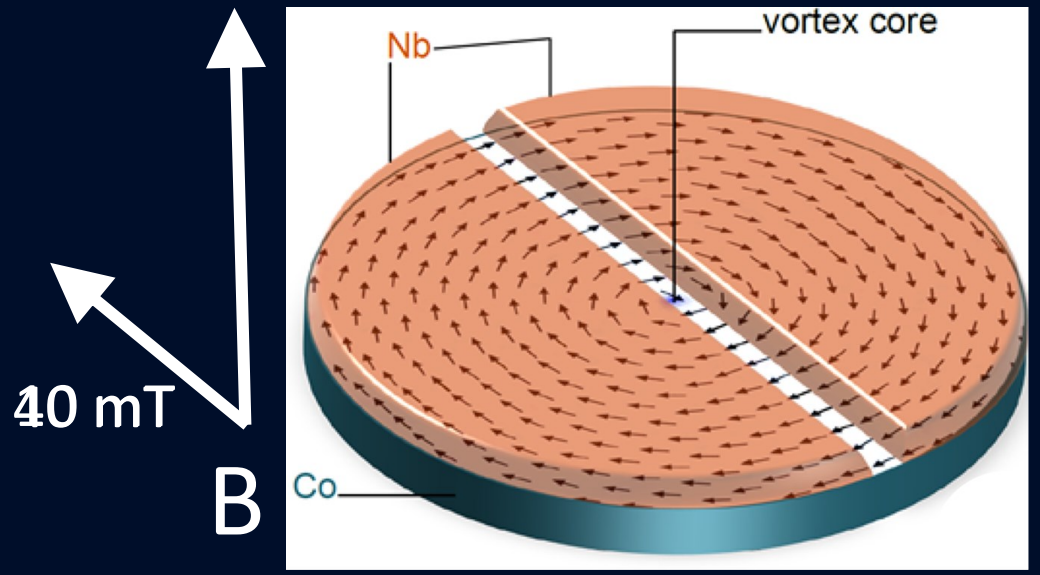
Condensed Matter > Superconductivity

[Submitted on 24 Mar 2023]

Triplet supercurrents in lateral Josephson junctions with a half-metallic ferromagnet

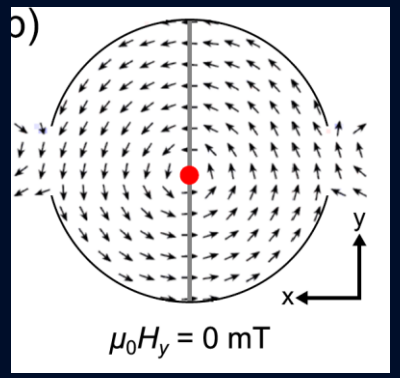
Yao Jungxiang, Remko Fermin, Kaveh Lahabi, Jan Aarts

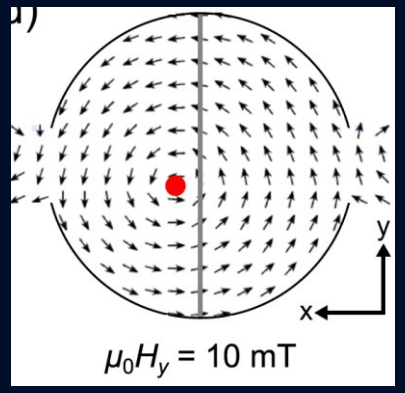
IP field dependence

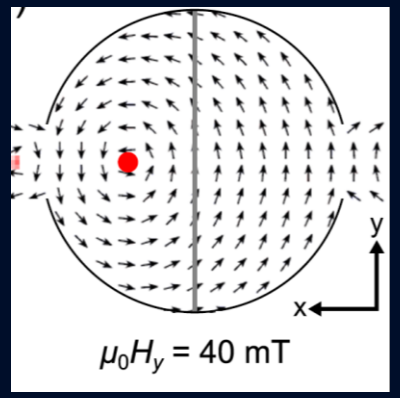


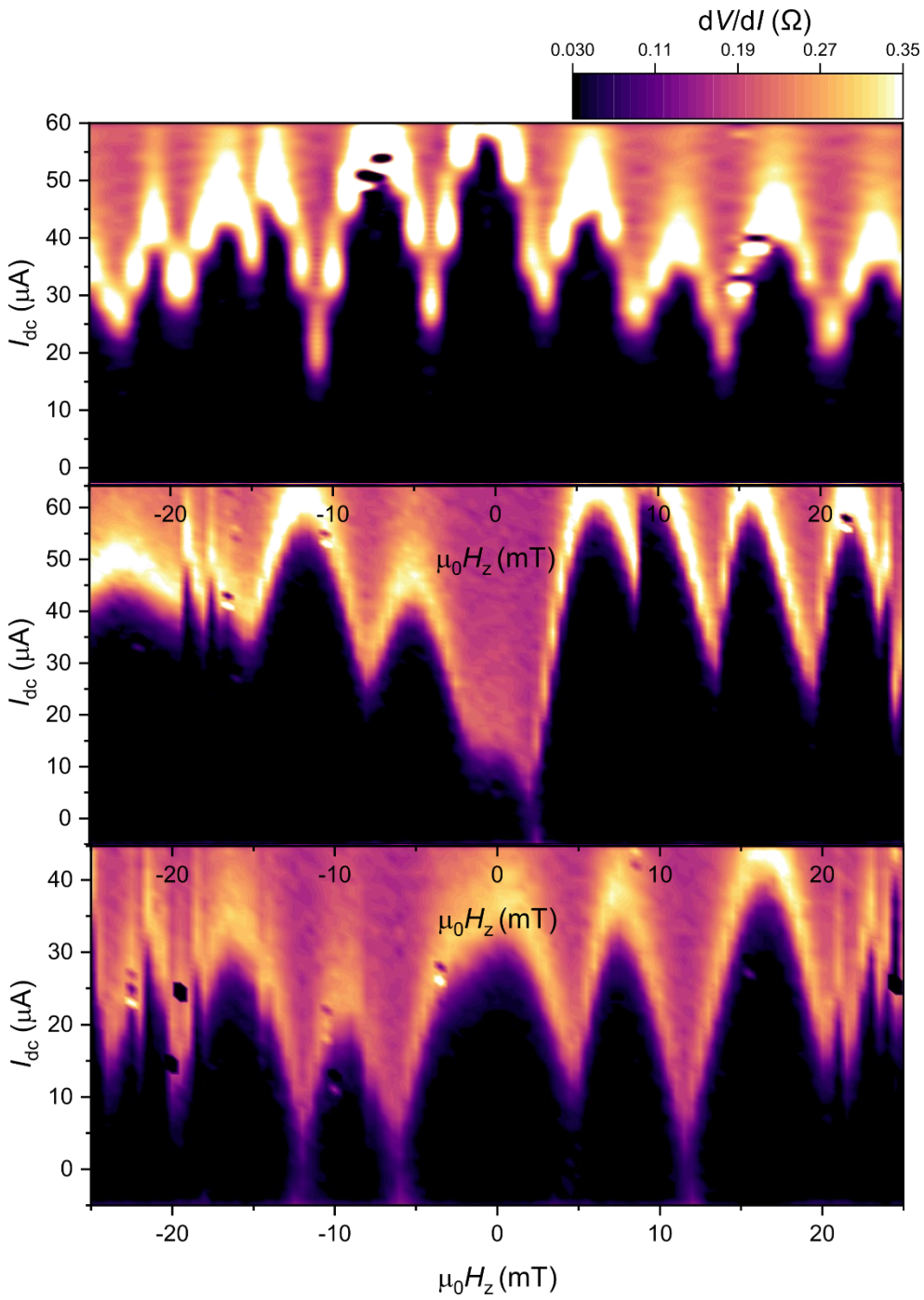
- 0-π squid behavior
- Reminiscent of 0-π segments

SC transport highly dependent on spin texture



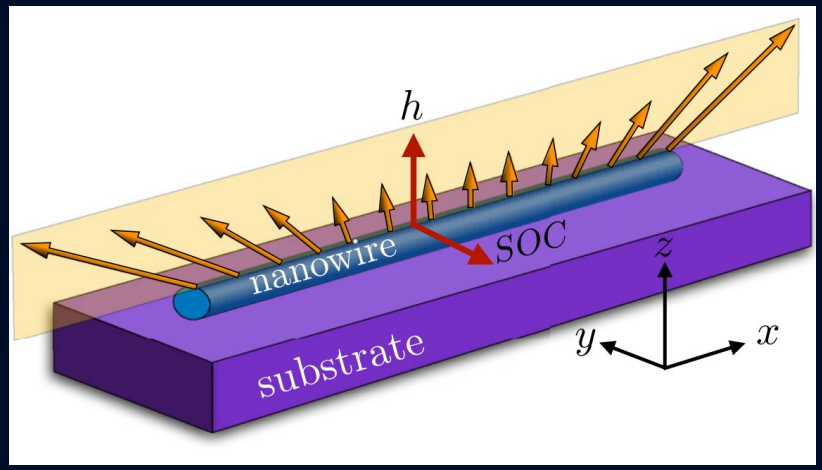




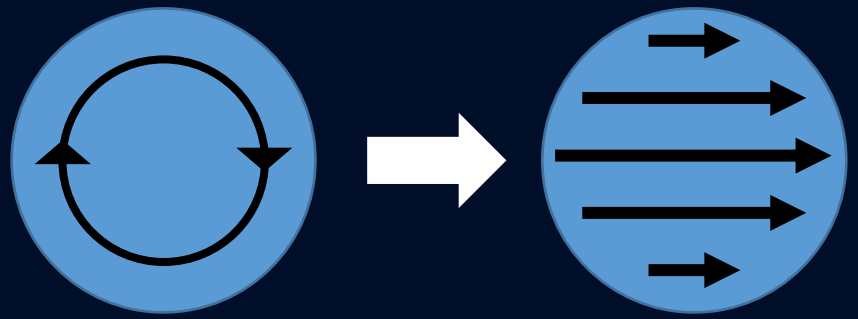


Tokatly et al., PRB, **100** (2019)

Triplet generation?



- Combination of spin texture and edges



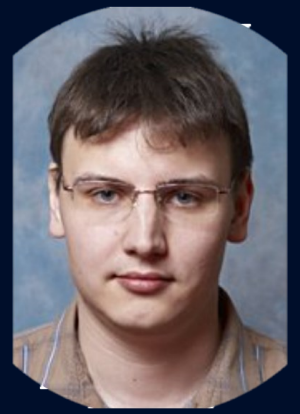
+ SOC

Vortex spin texture → Uniform magnetization + spin-orbit coupling (SOC)

$$\nabla_j \hat{f} \to \nabla_j \hat{f} + iZ_j[\hat{\sigma}_z, \hat{f}] = \hat{\boldsymbol{\sigma}}(\nabla_j \boldsymbol{f} - Z_j[\boldsymbol{z} \times \boldsymbol{f}])$$

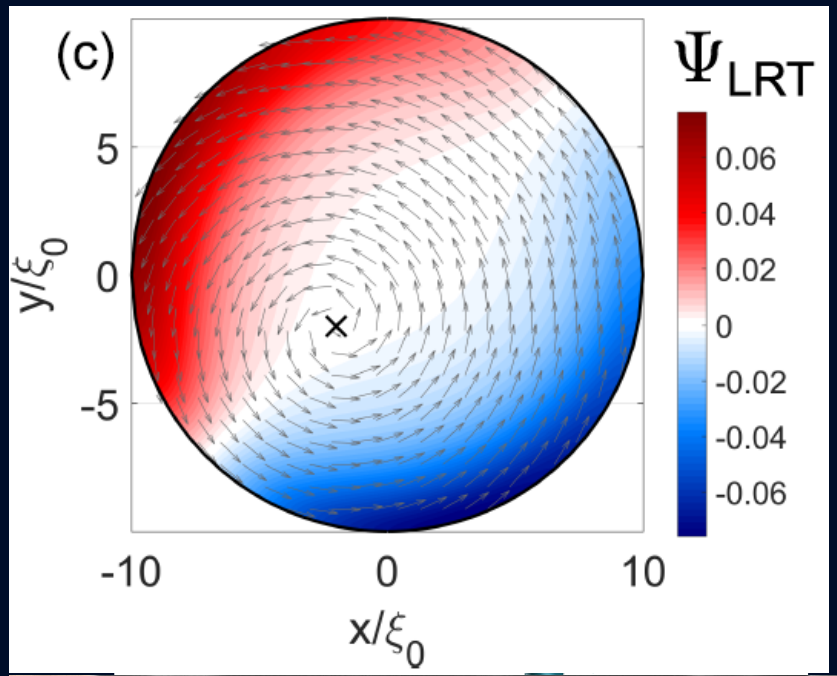
SOC generates a spin current (in SRT condensate)

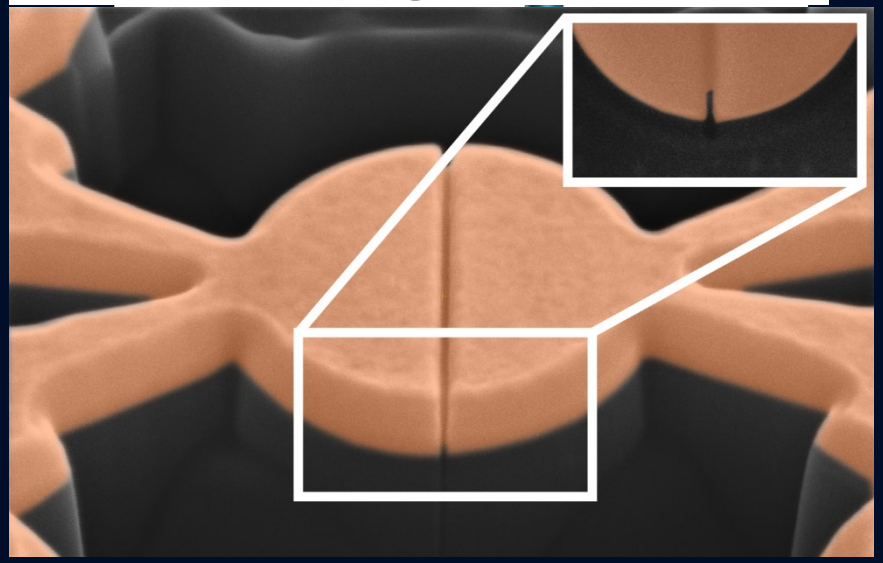
Spin current is converted into LRT at boundaries

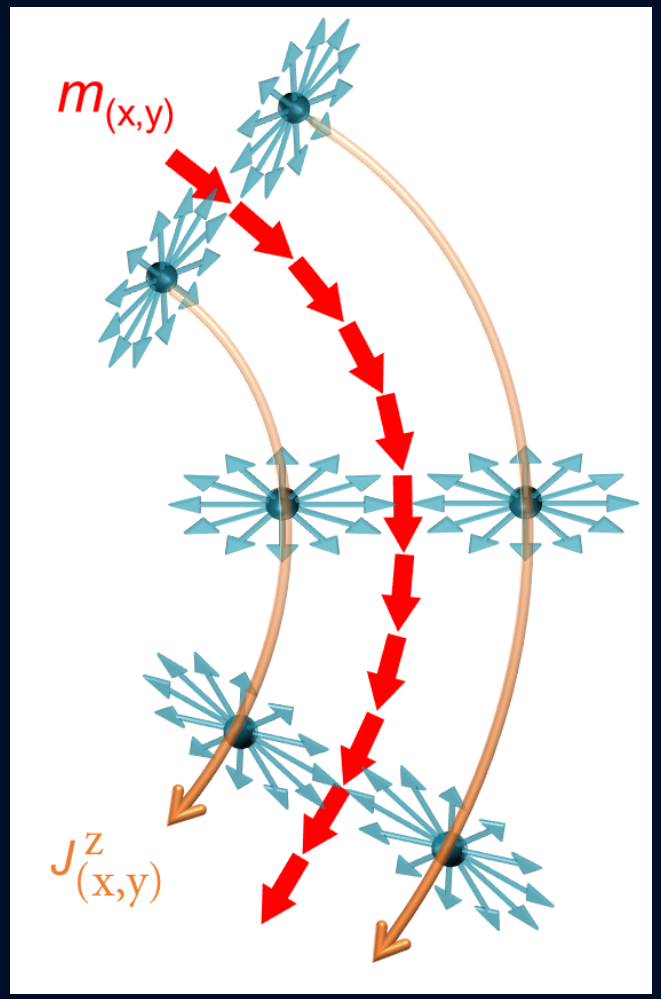


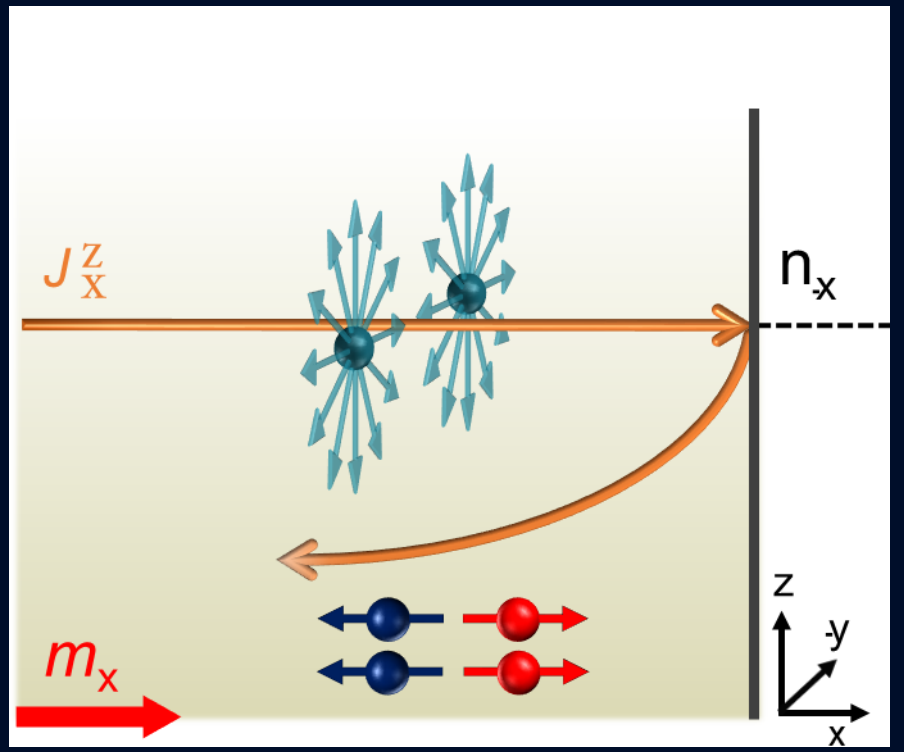
Mikhail Silaev

Triplet generation









Open questions:

- Triplet generation at the trench?
- Many current channels under IP fields

Conclusions on disks

- Spin-polarized triplets generated by a single ferromagnet with vortex magnetization
- Triplet transport in highly-confined rim currents at side of the disk
- High control over superconducting transport due to spin texture
- One more thing…

What about applications?

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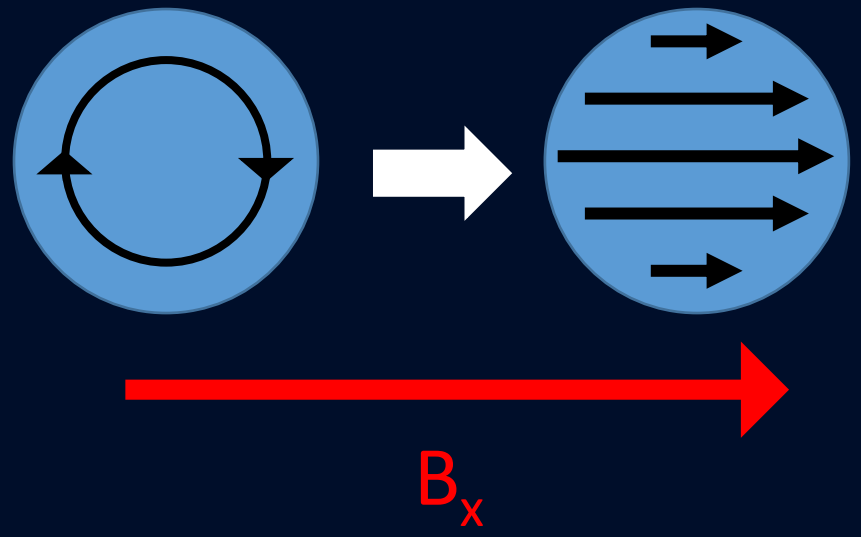
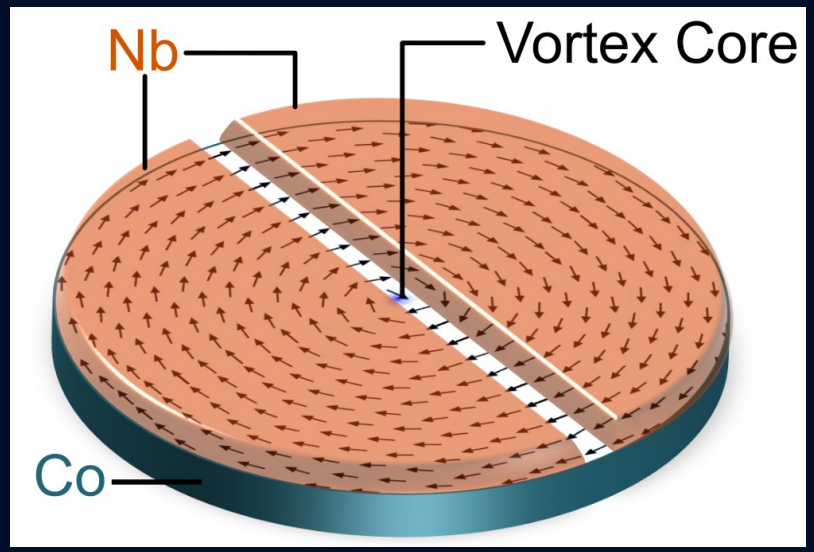
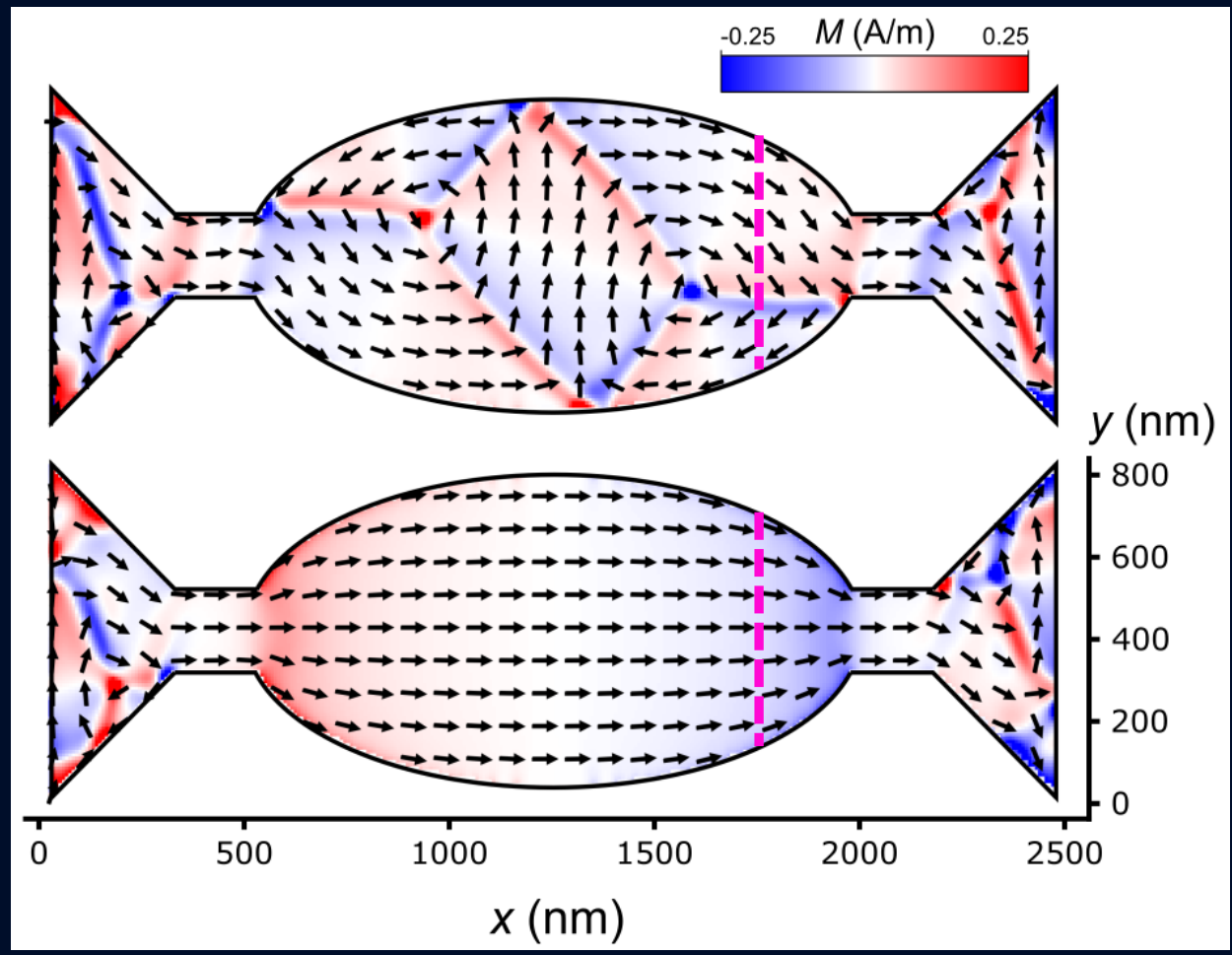
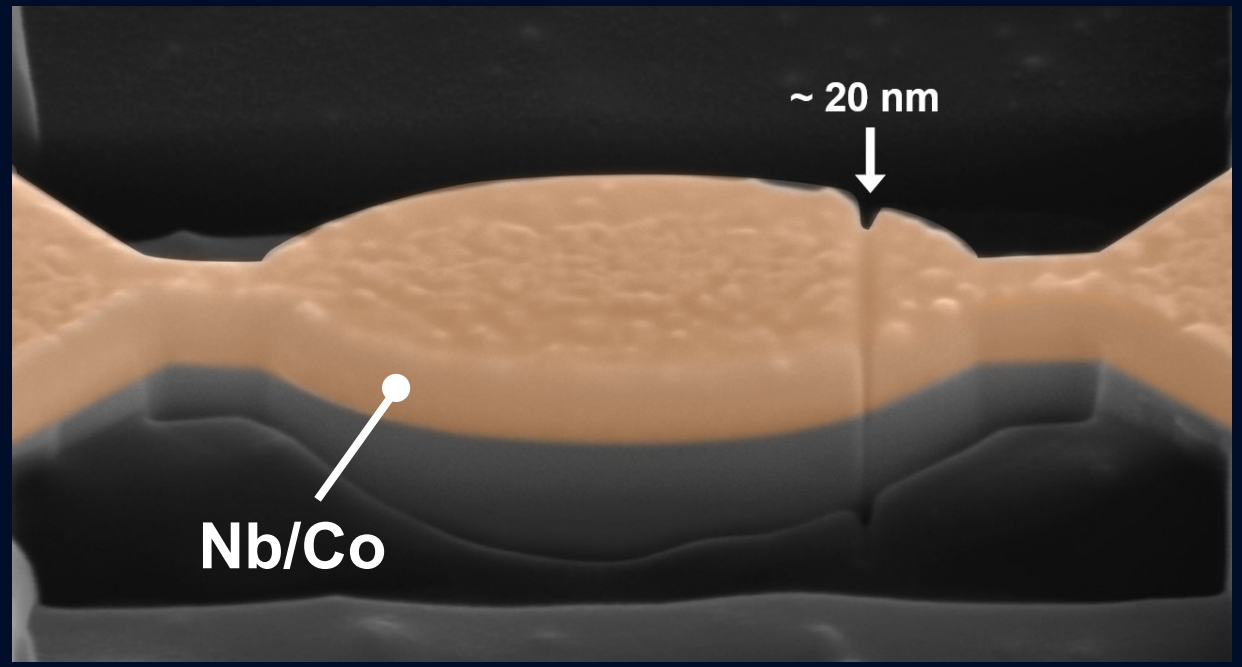


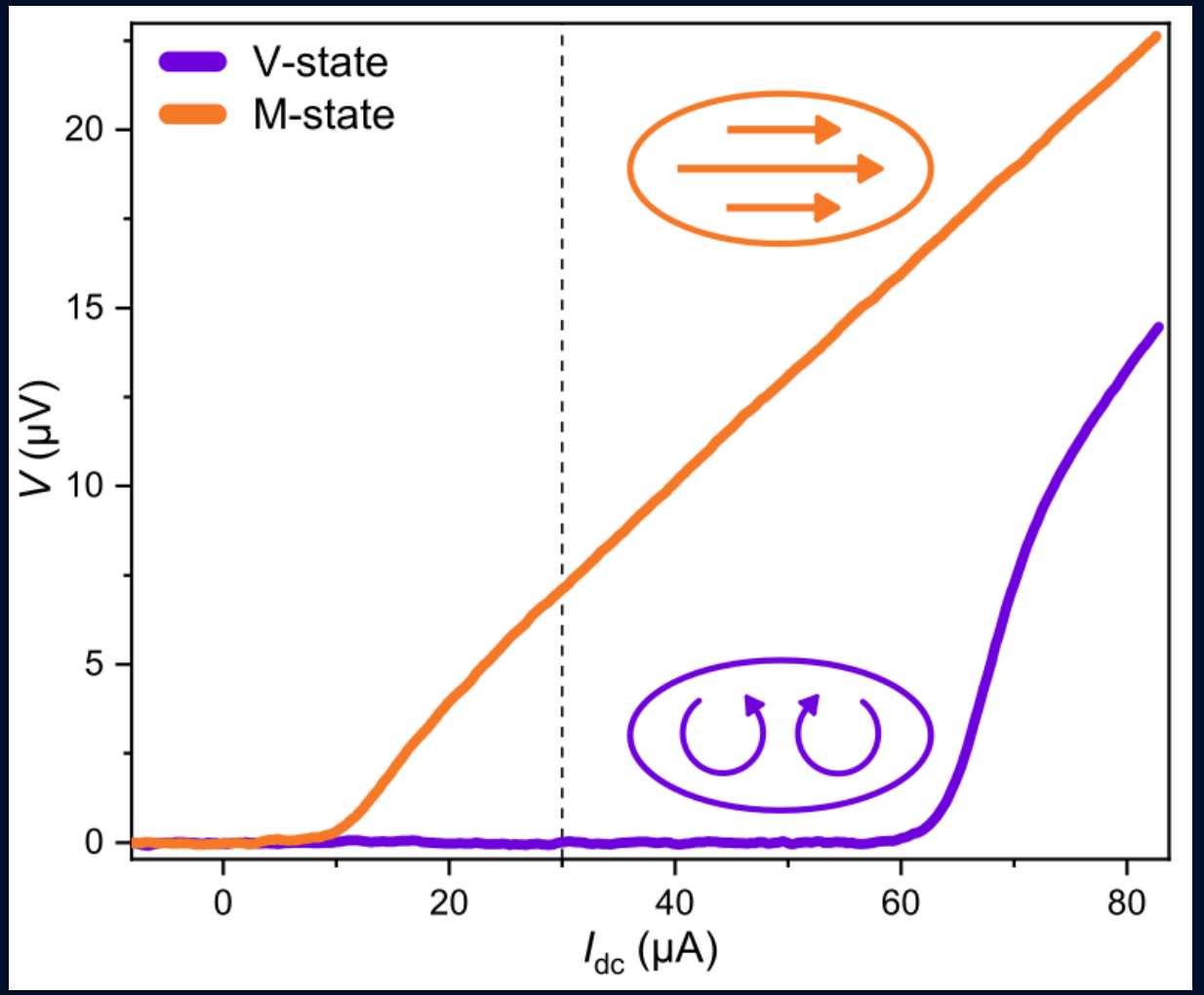
Elliptical devices





Bistability in transport: memory effect





Conclusions on ellipses

rf517@cam.ac.uk

- Storing information in the spin texture of a single ferromagnet
- Robust electrical read-out
- Stable at room temperature
- Relative low energy switching

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R. Fermin, N. M. A. Scheinowitz, J. Aarts, and K. Lahabi
Phys. Rev. Research **4**, 033136 – Published 19 August 2022

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arXiv > cond-mat > arXiv:2303.13922

Condensed Matter > Superconductivity

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