Spin-orbit interaction and induced superconductivity in an one-dimensional hole gas

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FAM

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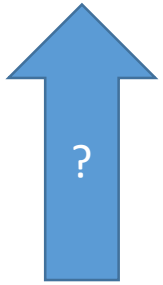
Outline

- Introduction and Motivation
- Superconductivity and Kondo Effect
- Andreev Level and Reflections
- Landé g-factor Anisotropy and Direct SOI
- Hard Superconducting Gap
- Summary and Conclusions

Introduction and Motivation

Goal: Topologically Protected Majorana Bound States



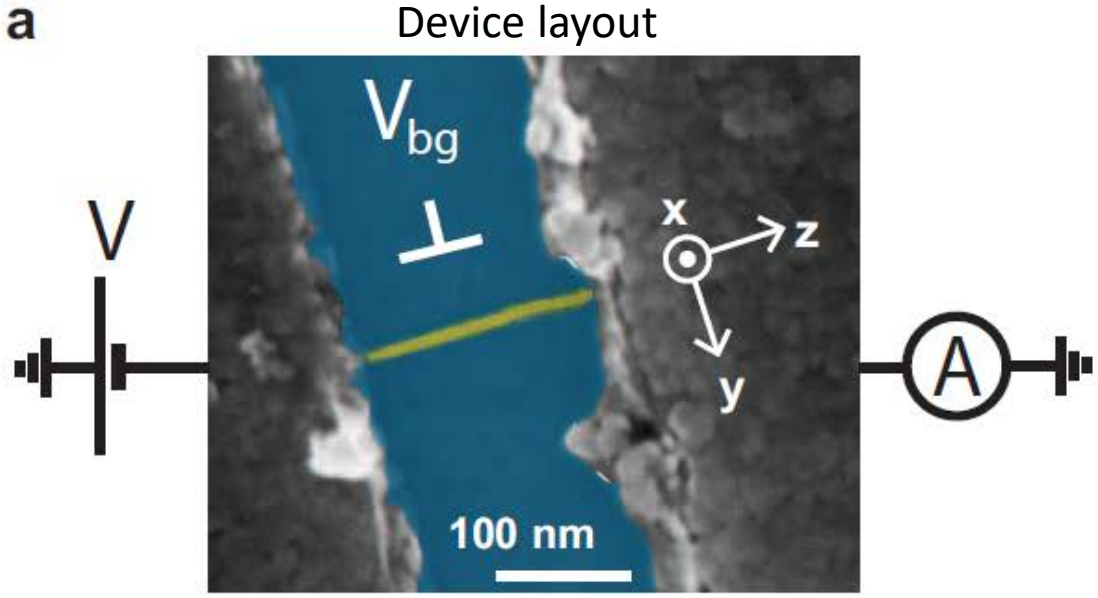
Ingrediants:

1. Low dimensional semiconducting structures
2. Strong spin-orbit interaction
3. Induced superconductivity

Promising candidate: One-dimensional hole gas in Ge/Si core/shell NWs

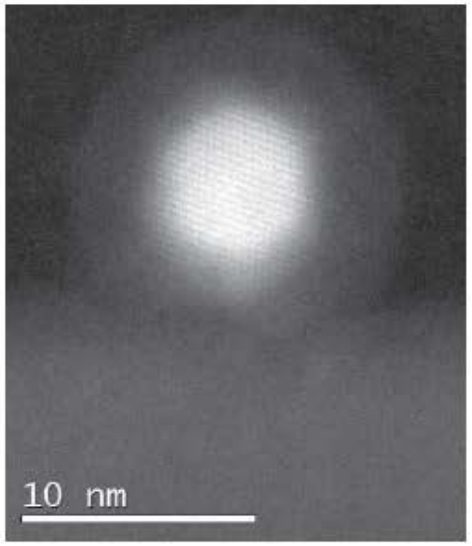
Sample Design and Properties

SEM
Device layout



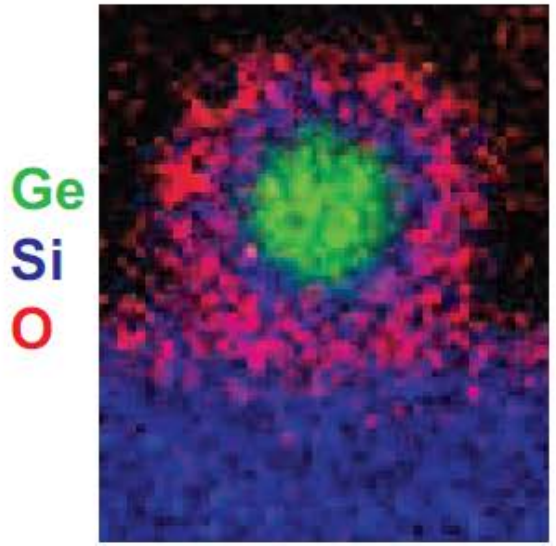
- QD formed between contacts
- Al leads
- Wafer: Si/SiN_x

TEM
cross section of wire



- Ge core (r = 3 nm)
- Crystal direction [110]

X-ray Spectroscopy
Elemental analysis



- Pure Ge core
- Si shell (1 nm)
- Amorphous silicon oxide shell (3 nm)

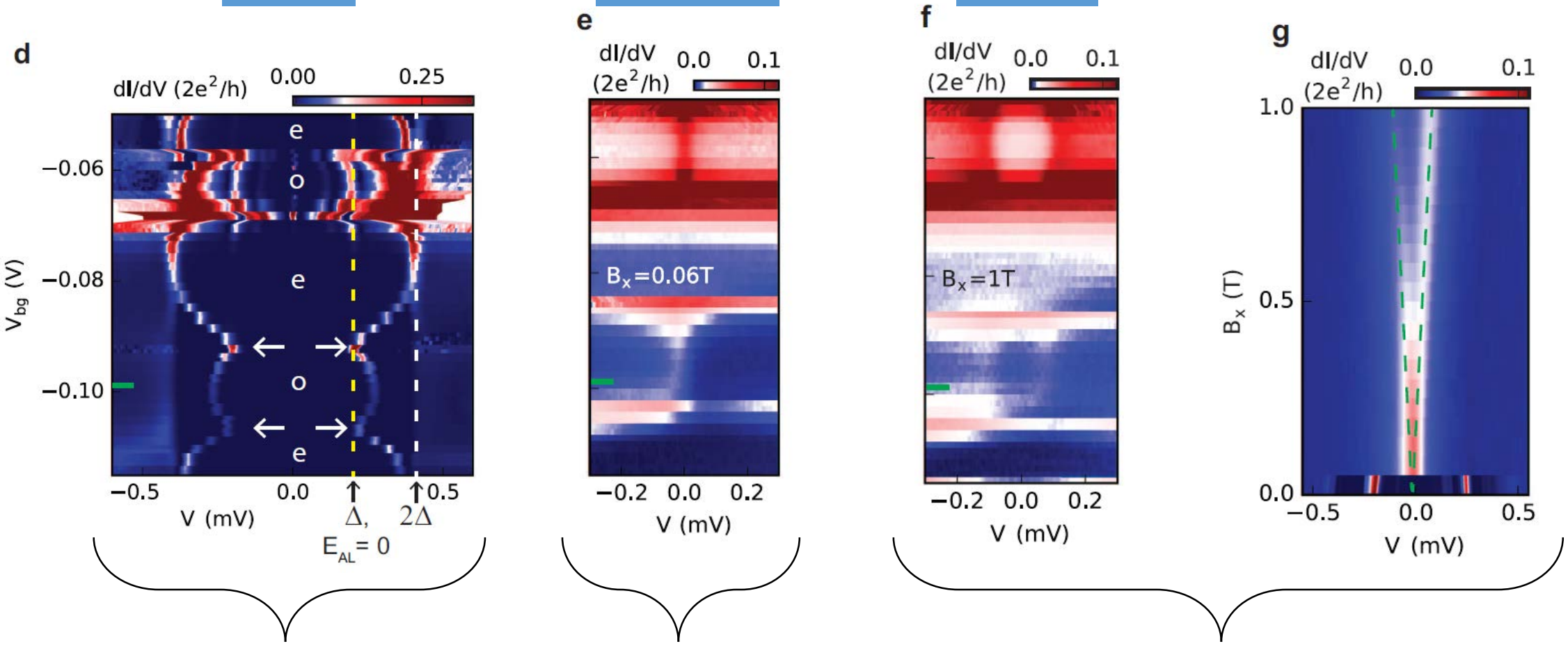
Remark: sample annealing (180°C) -> contact resistance drops from MOhm to kOhm regime

Superconductivity and Kondo Effect

B_x = 0 T

B_x = 60 mT

B_x = 1 T

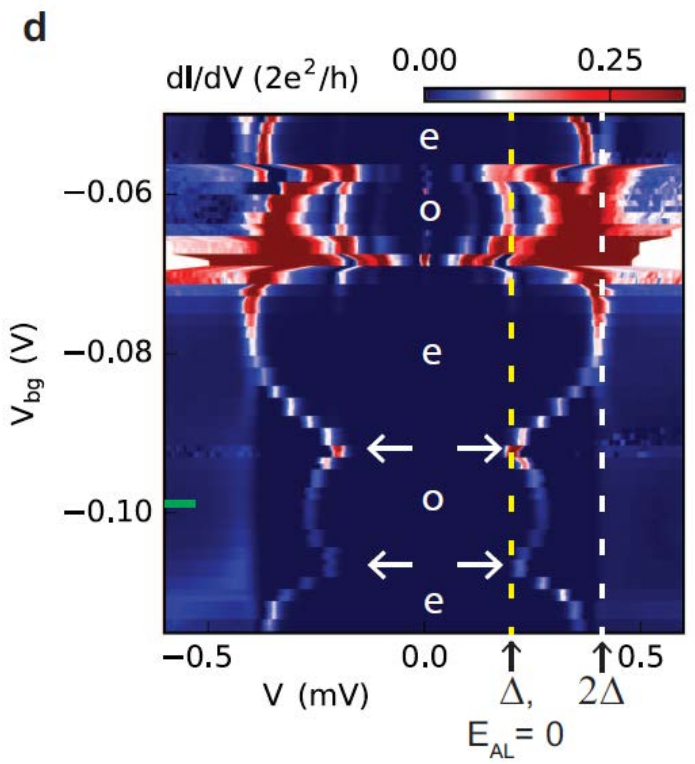


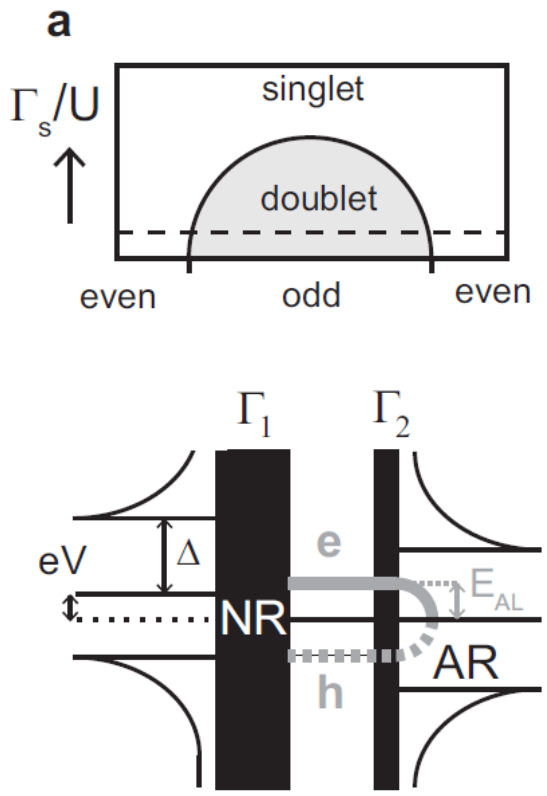
- Superconducting gab 2Δ = 380 μeV
- Even (e) – Odd (o) structure

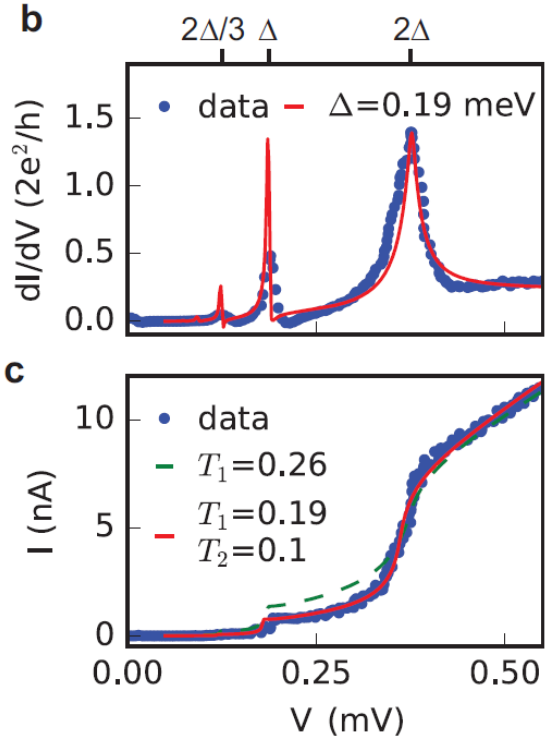
- Suppressed SC
- Zero-bias peak for o parity
- Kondo effect

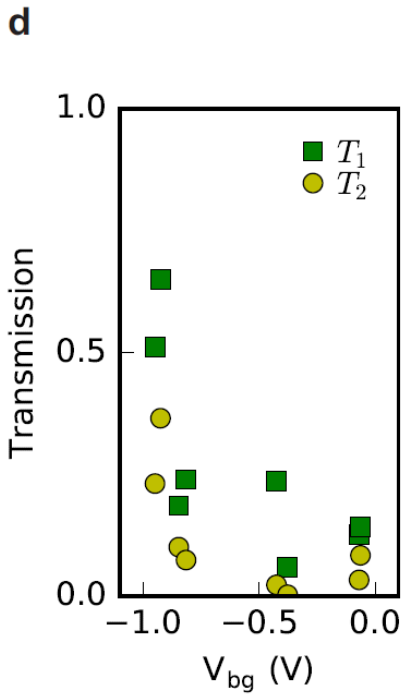
- Kondo peak splits
- $E = 2g\mu_B B$
- Extract g = 1.9

Andreev Level and Multiple Andreev Reflection







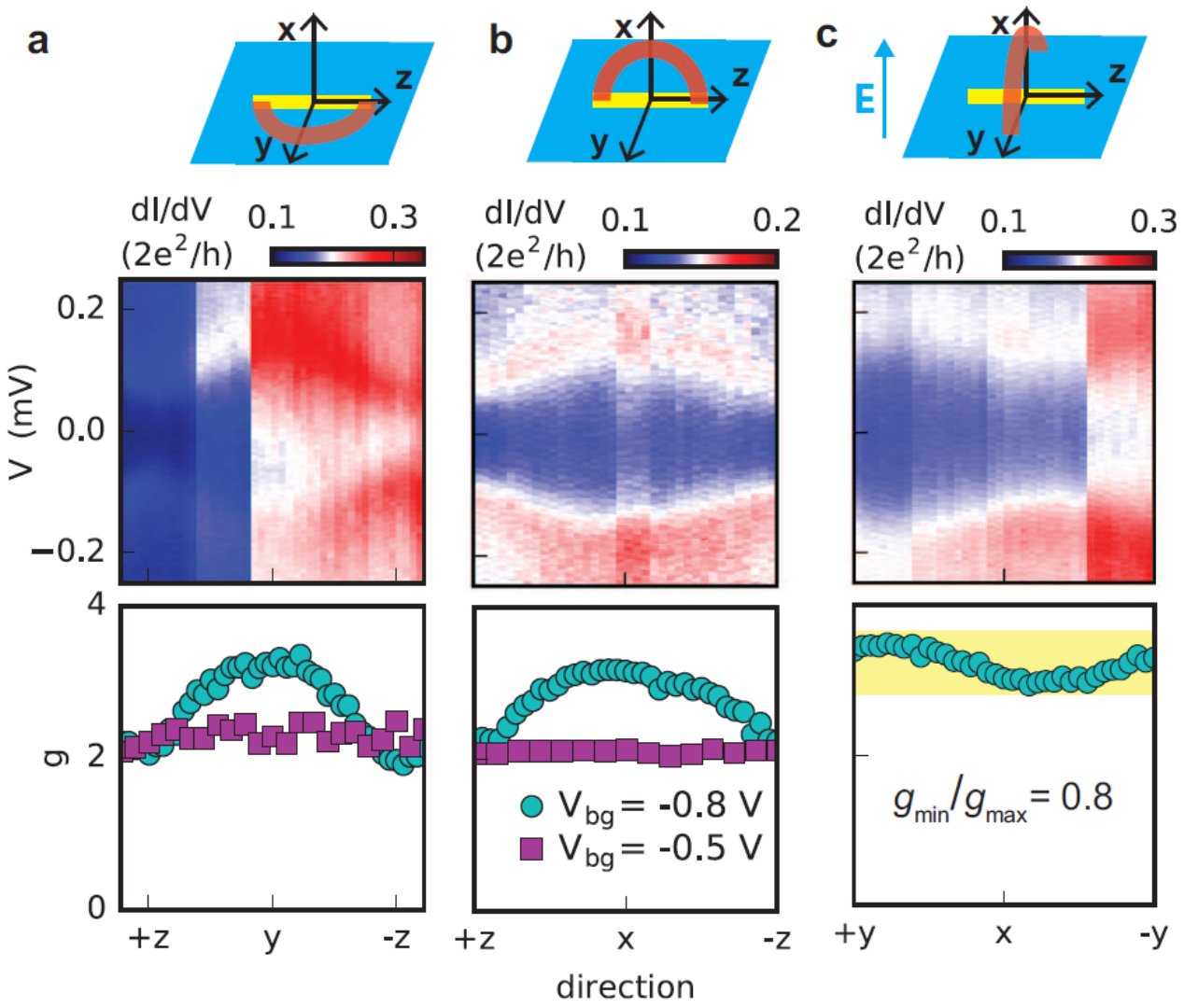


- Andreev Level (AL)
  Energy transition ground to excited state
- Ground state switches btw singlet and doublet
- Upper part: multiple Andreev reflections (MAR)

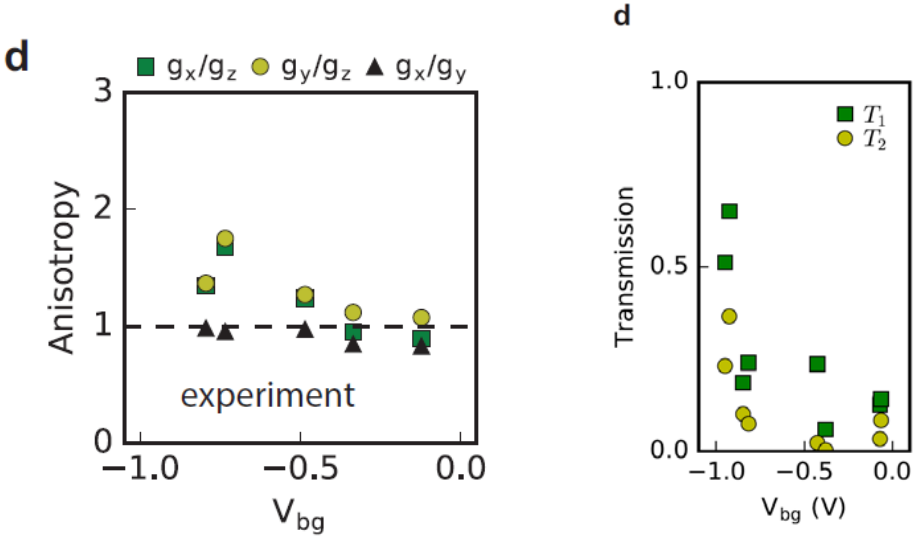
- AR at Γ_2 and NR at Γ_1
- Left lead tunneling spectroscopy probe of DOS
- $E_{AL} = 0$ -> measure it at $eV = \Delta$
- Ground state transitions indicated “->”

- Fitting of dI/dV used to extract Δ
- Fitting of I to extract transmission T_1 and T_2
- Increase of T below V_{bg} = -0.8 V due to the increase of E_F and Γ_1 and Γ_2

g-factor anisotropy



- G-factor from Kondo peak splitting
- Strong anisotropy at V_{bg} = -0.8 V
- Maximum g = 3.5
- Isotropic g at V_{bg} = -0.5 V

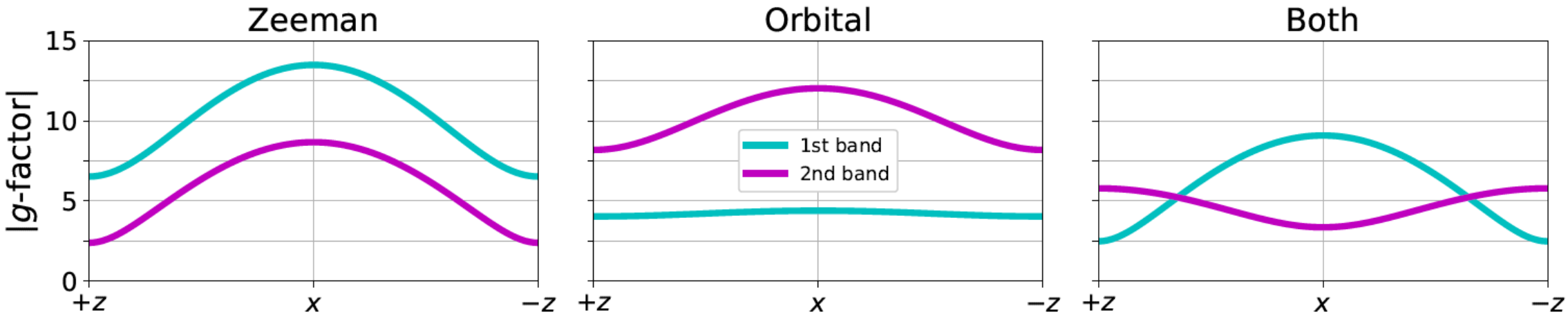


- Increase of anisotropy sets in at V_{bg} = -0.7 V
- Correlated with transmission

<u>Hypothesis:</u> transition from isotropic to anisotropic behavior related to the occupation of two bands in the NW

Zeeman and Orbital Effect

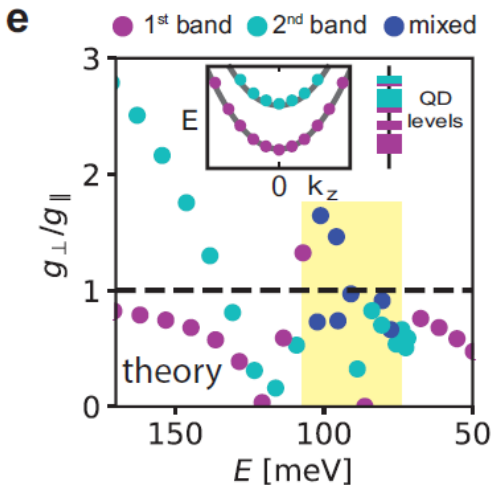
- Theoretical model: infinite wire



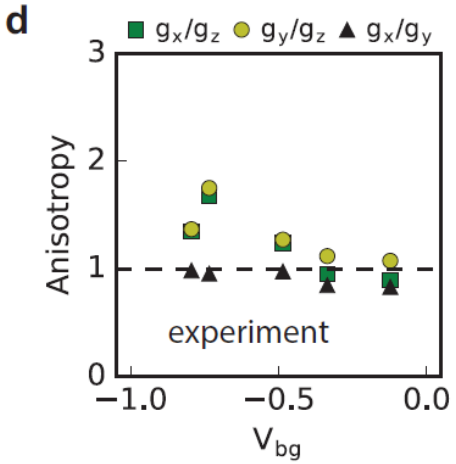
- Two contributions to the anisotropy: Zeeman & Orbital
- Zeeman similar for both bands
- Orbital contribution differs

Observed isotropic and anisotropic g due to orbital effect

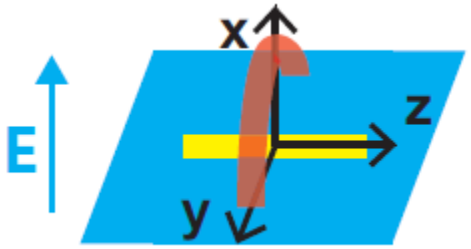
Nature of SOI

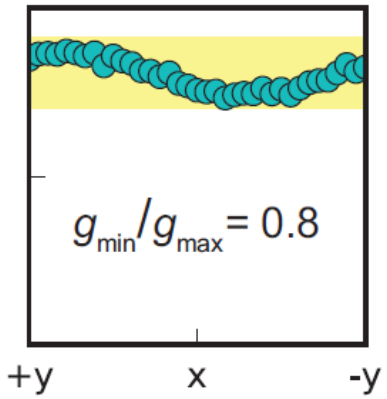


- Confinement along NW included
- Some QD levels are a mixture of both bands
- Qualitative agreement with experiment

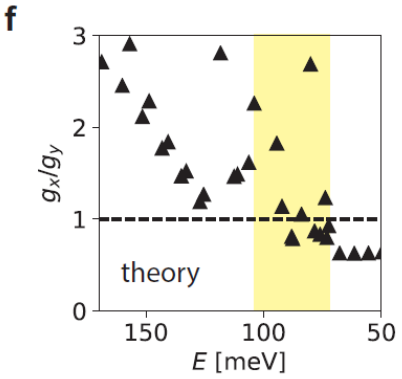


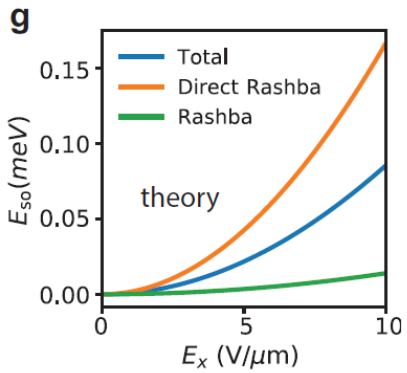
Magnetic field rotation in xy-plane (parallel and perp. to E-field)





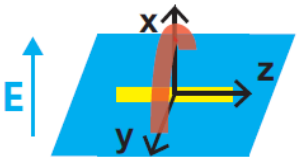
- Anisotropy with respect to E is a signature of SOI





Direct Rashba SOI dominating

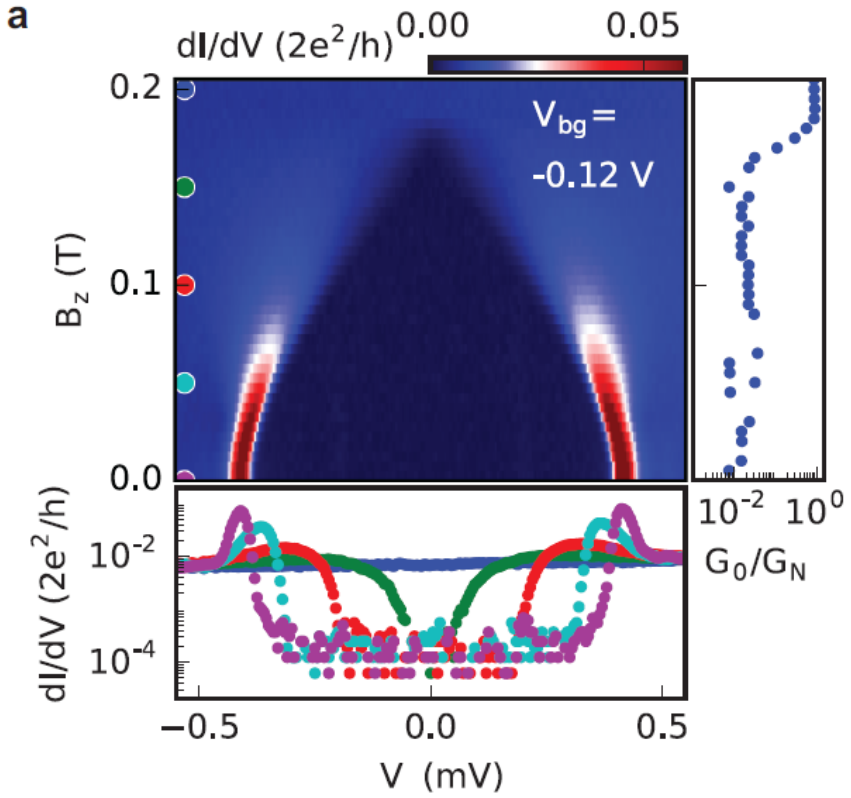
Hard Superconducting Gap



Critical fields:

- $B_{C,Z}$ = 220 mT
- $B_{C,y}$ = 220 mT
- $B_{C,X}$ = 45 mT

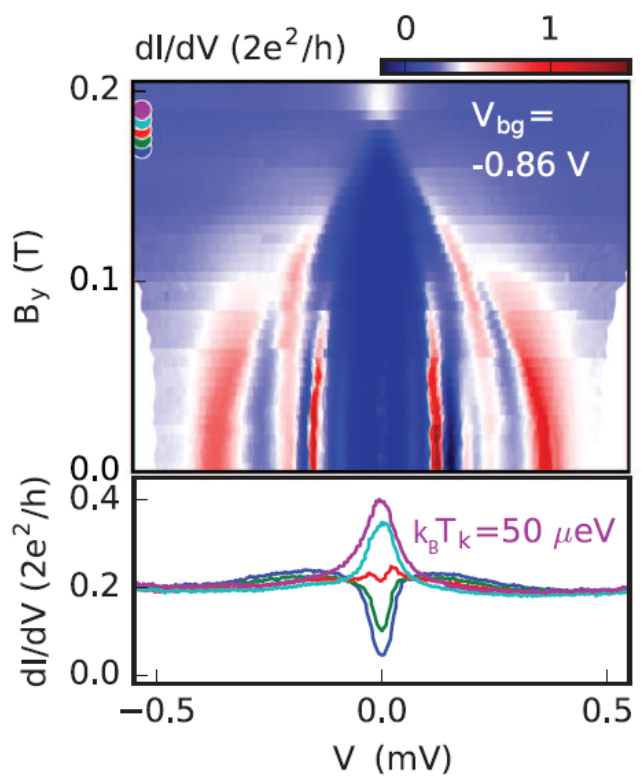
Low conductance regime



- Conductance suppression remains as the gap size decreases towards B_C

→ Hard superconducting gap

High conductance regime



- T increased -> AR processes cause significant conductance inside the SC gap
- Conductance suppression: ill-defined measure of DOS and quality of induced SC
- Use Kondo peak to examine DOS

$k_B T_K \leq \Delta$

- Existence and size of Kondo peak: indication of quasiparticle DOS
- Kondo peak only appears after gap is closed

↓

Hard superconducting gap

Summary and Conclusions

- Observation of:
  - Andreev levels with ground state transitions
  - SOI from the coexistence of two modes in the NW
  - Hard SC gap
- Promising candidate for creating a 1D topological SC

Thank you for your attention!