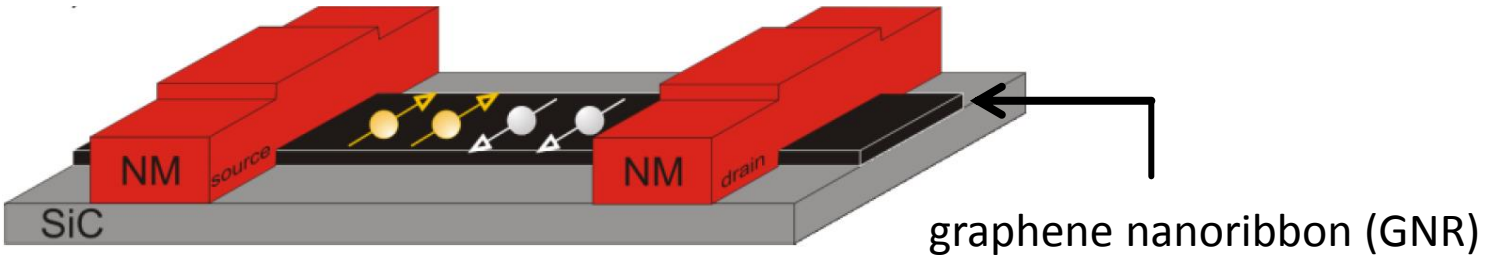
# TAILSPIN

***Tailoring spin-interactions in graphene nanoribbons for ballistic fully spin-polarized devices***

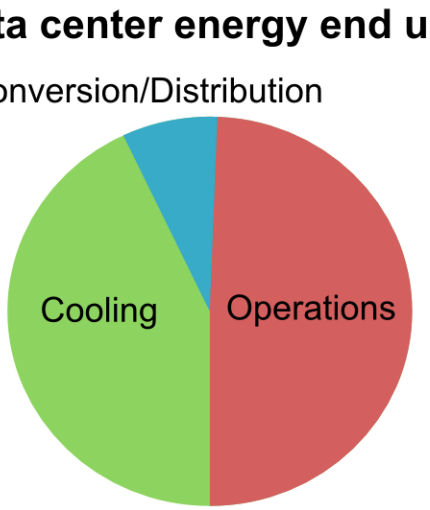


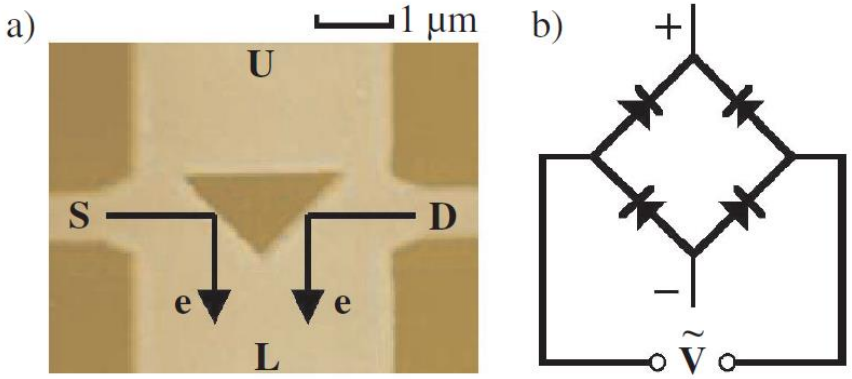

*Christoph Tegenkamp, University of Hannover*

# The future of electronic devices

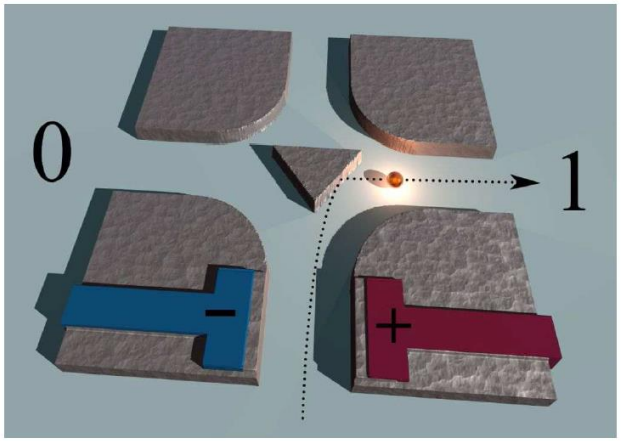
**Ideal future electronic device:**

- Low heat dissipation
- High operating speed
- Large range scalability

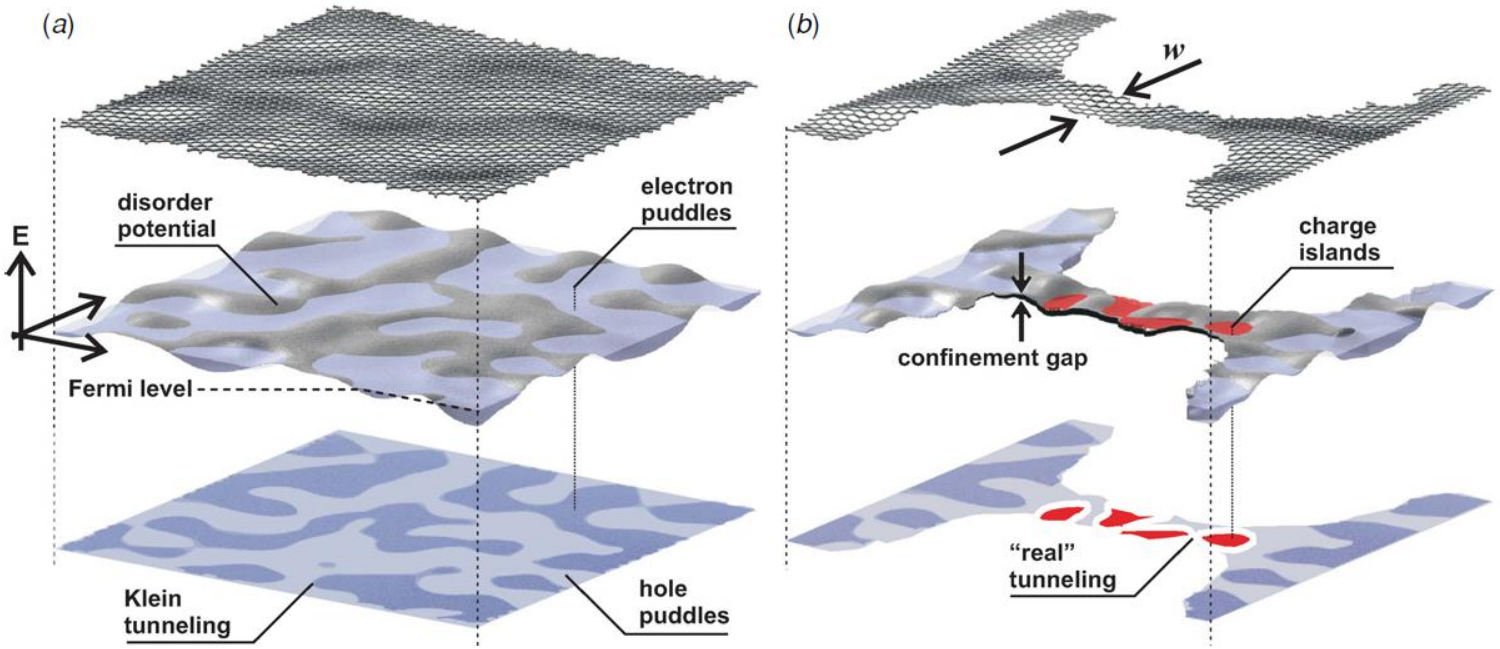



Song et al., PRL **80** (1998)



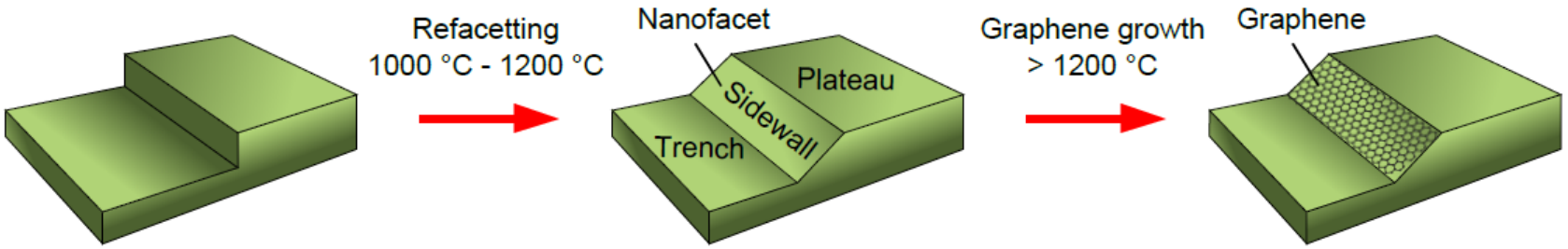
# Lithographic etching of GNRs

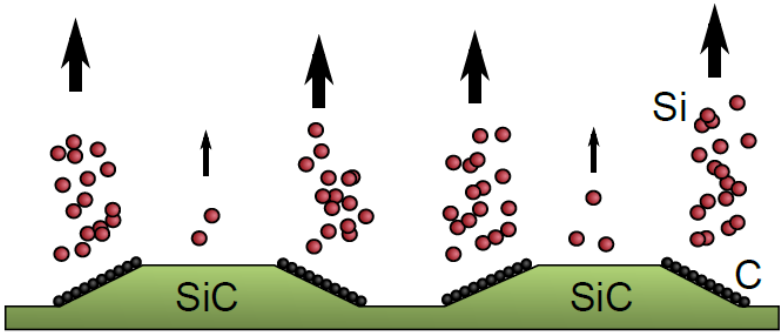



Molitor et al., SST **25** (2010)

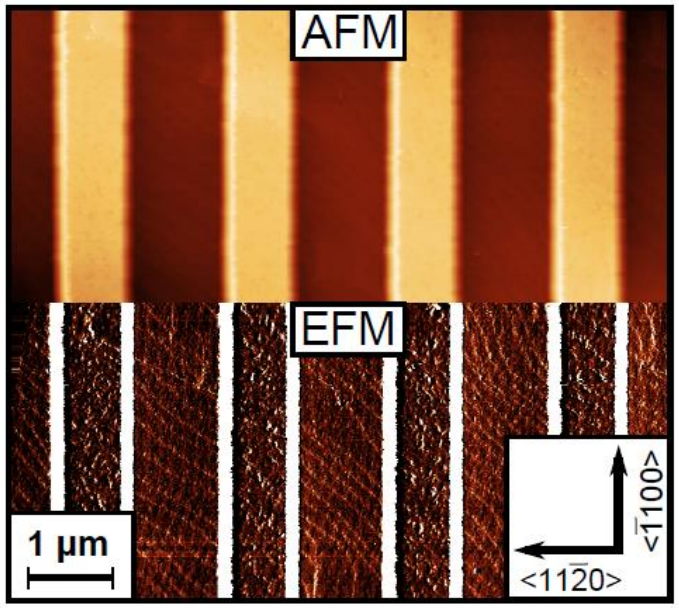
→ **Coulomb blockade**

# Self-assembled growth of zig-zag GNRs



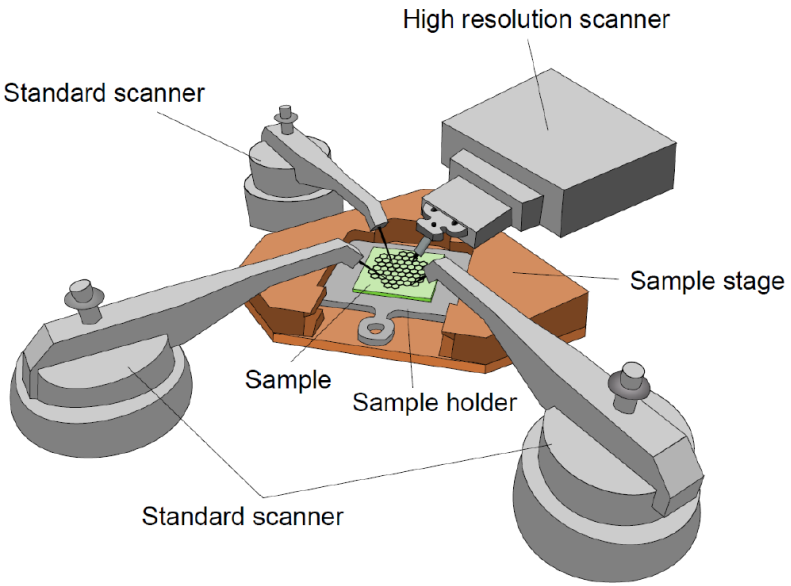




**Idea:** Sprinkle et al., Nature Nano. **5** (2010)

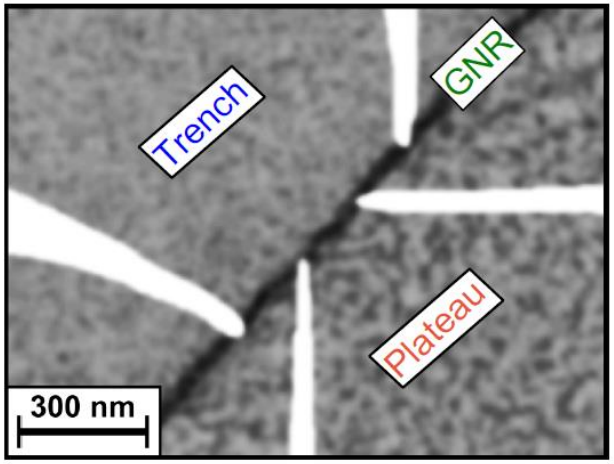


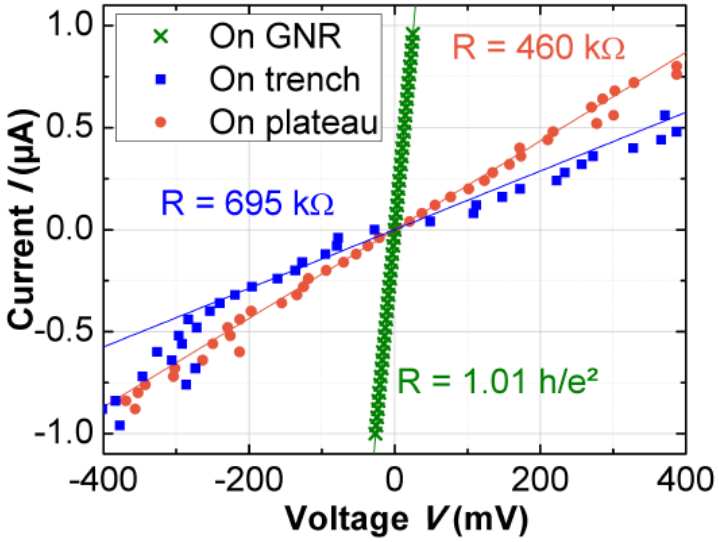

Baringhaus et al., APL **106** (2015)

# Local electronic transport

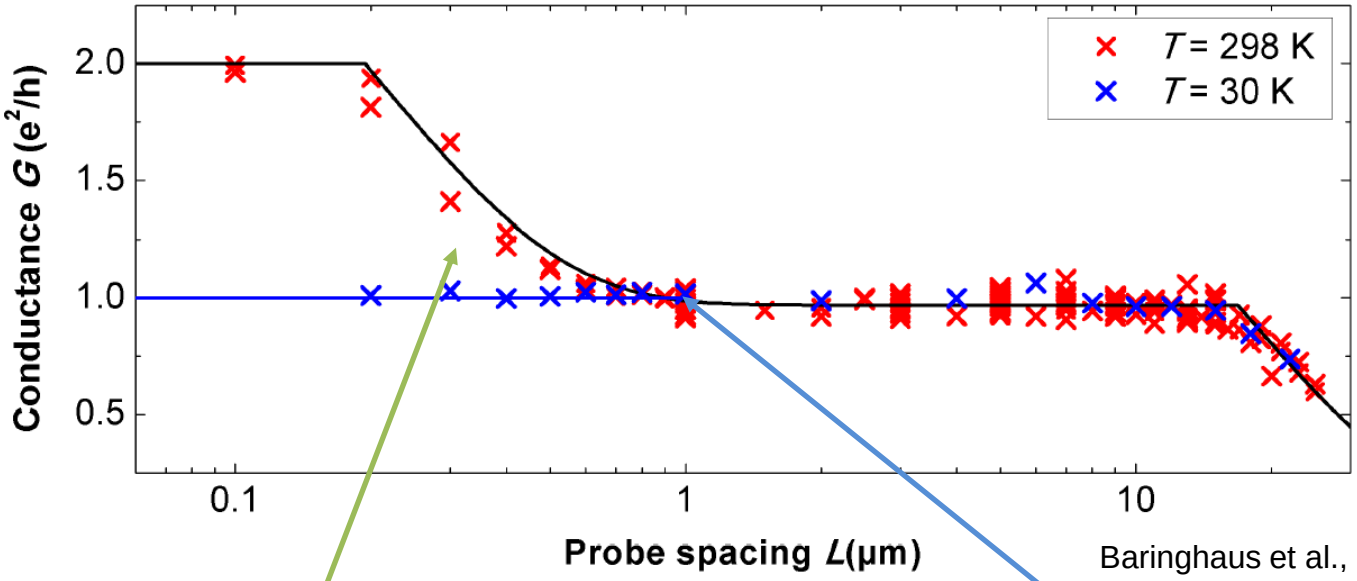



- 4 STM tips
- HR Gemini type SEM with a resolution < 4 nm
- $T_{sample}$ < 26 K

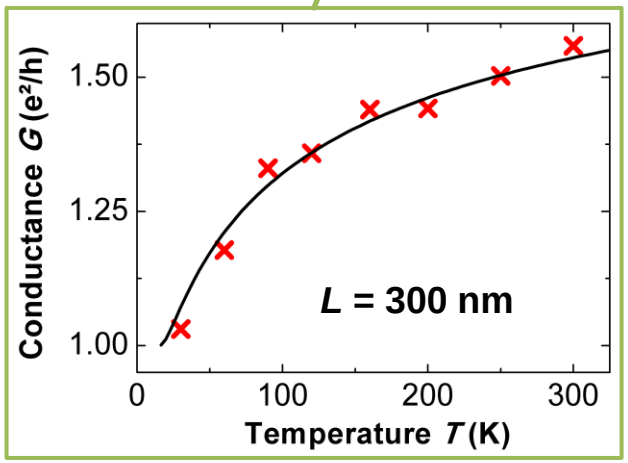


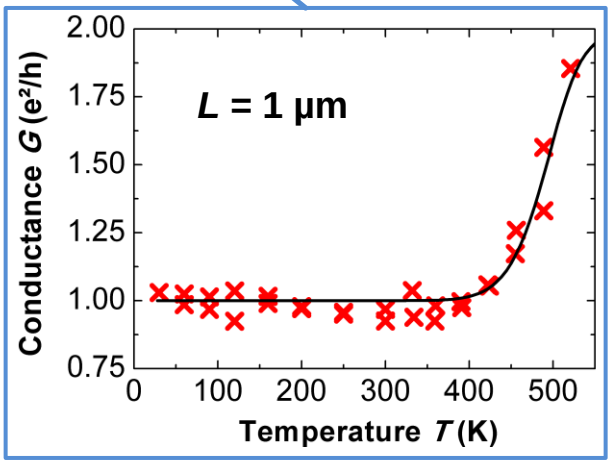



# Exceptional ballistic transport



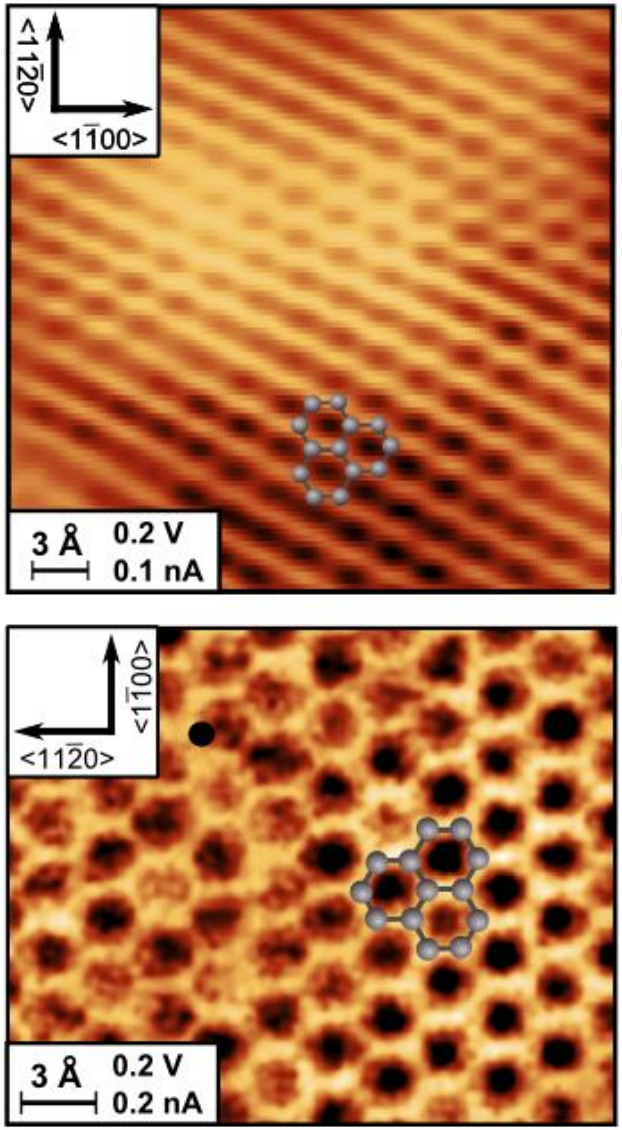

Baringhaus et al., Nature **506** (2014)

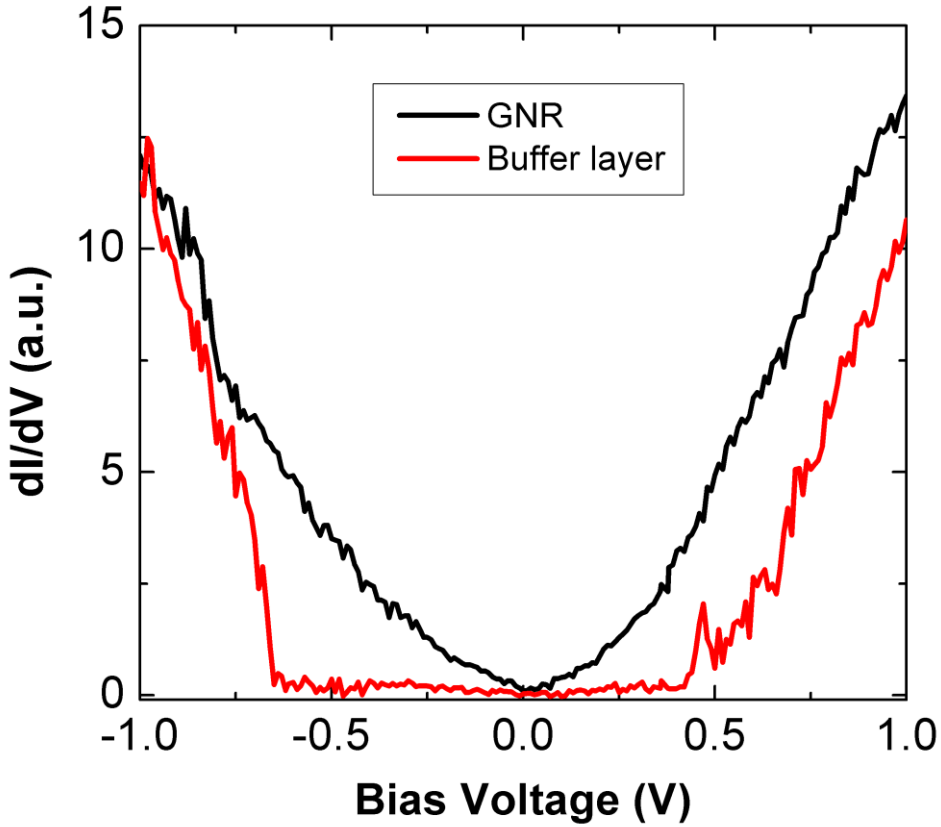



**Ballistic transport through a single non-deg. channel at RT**

# Morphology and DOS

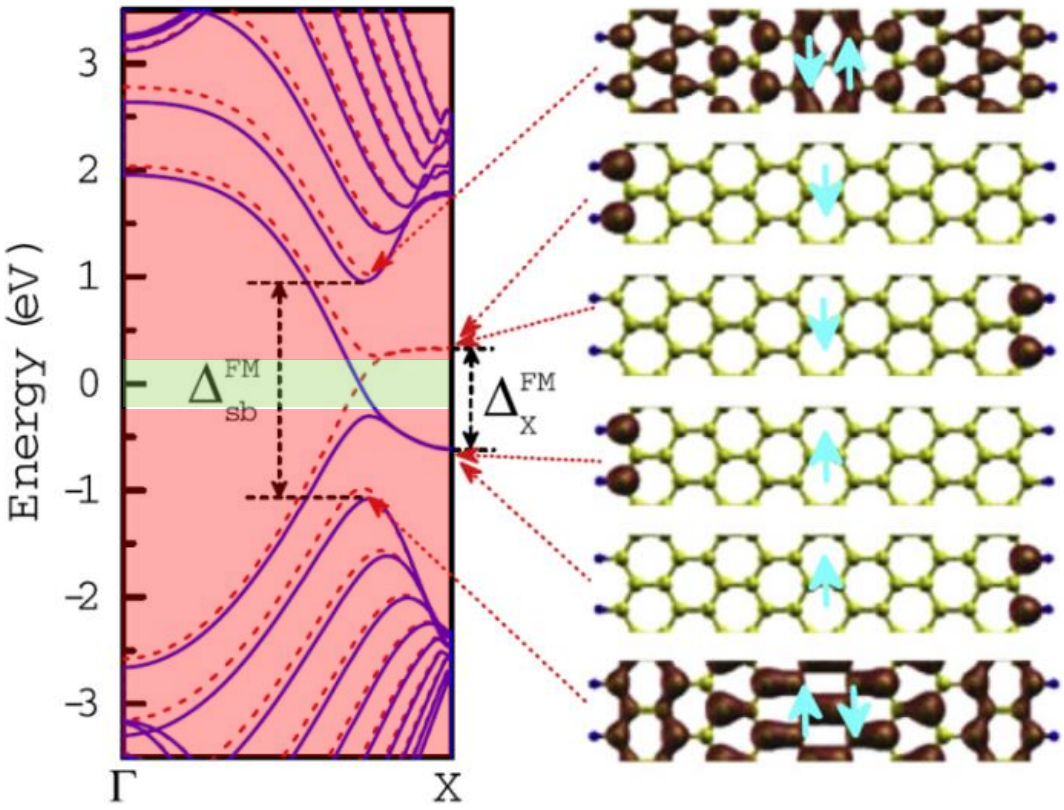



**Sidewall GNR are:**

- **always zigzag**
- **charge neutral**

# Perfectly conducting channel



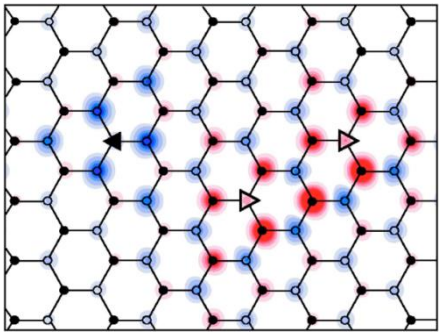

**Theory: spin-polarized edge channels in in zig-zag GNRs**

Huang et al., J. Phys. Condens. Matter **25** (2013)

# Origin of spin polarization

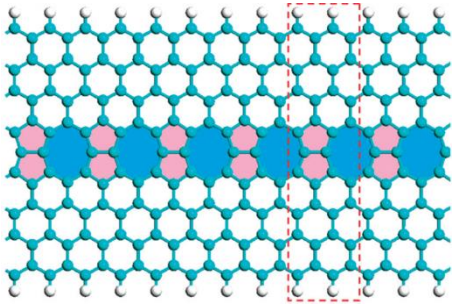
## Defect induced magnetism

### Adsorbates

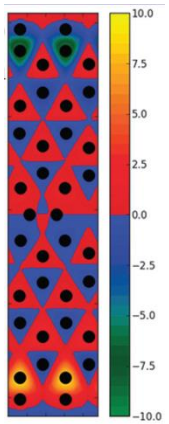


Yazyev et al., PRB **75** (2007)

### Line defects

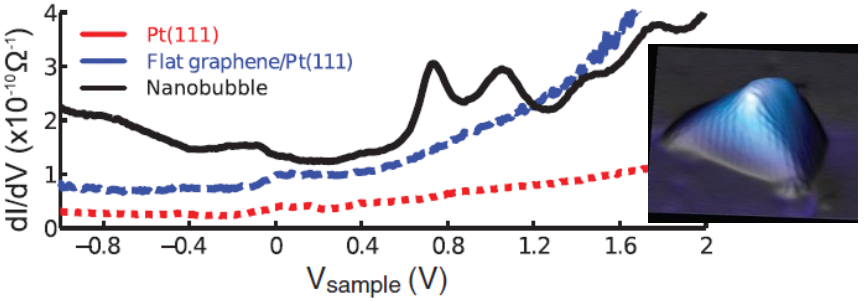


Tang et al., PCCP **17** (2015)



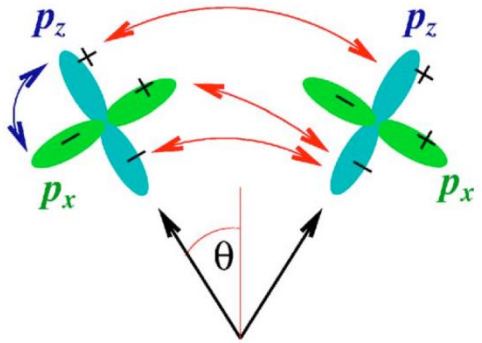

## Curvature

### Pseudo-magnetic fields




Levy et al., Science **329** (2010)

### Spin-orbit coupling

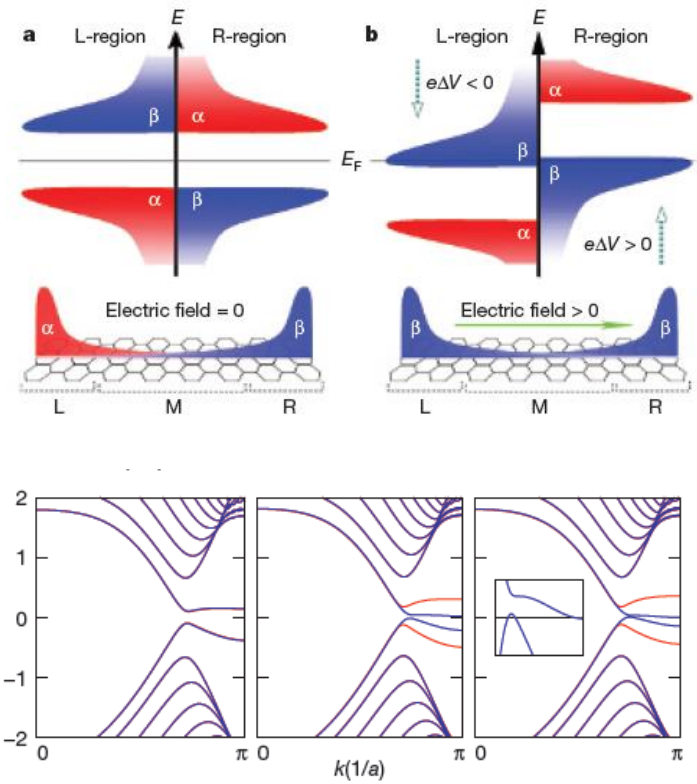



Huertas-Hernando et al., PRB **74** (2006)

# Origin of spin polarization II

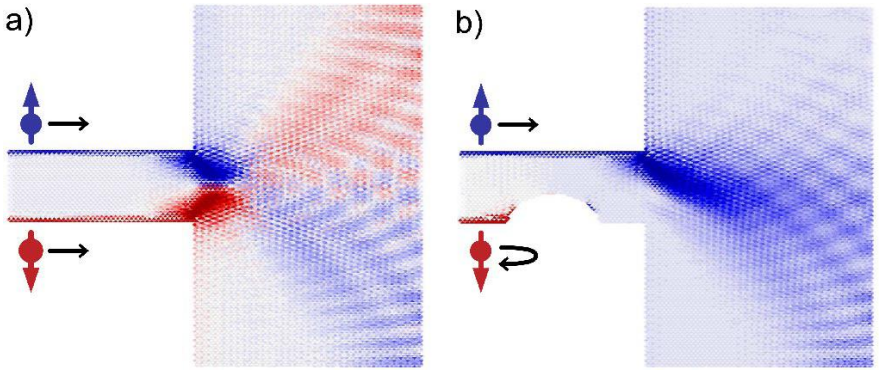
## Spin polarized edge states

### Half-metallicity




Son et al., Nature **444** (2006)

### Edge roughness




Wimmer et al., PRL **100** (2008)

# Relevant aspects addressed in TAILSPIN

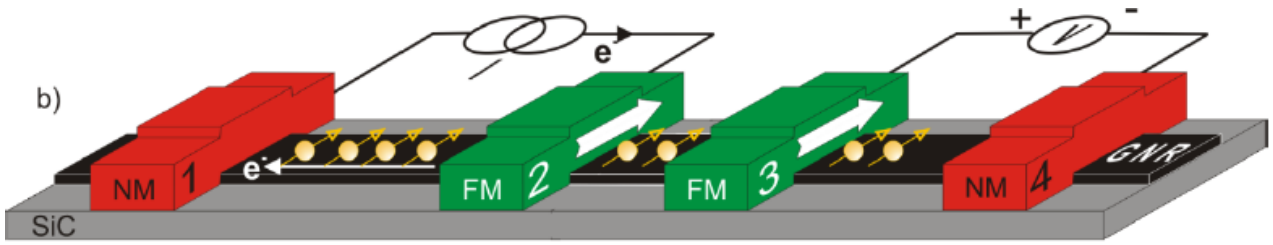
**I) Nanostructuring & functionalization**
*SiC-mesa via e-beam and optical lithography*

**II) Structure**
*STM and LEEM, edge orientation, curvature effects, relevant defects, adsorption sites, growth kinetics,....*

**III) Electronic structure & excitations**
*edge states, spin-resolved STS and ARPES to probe spin states, tuning by adsorption and intercalation RIXS,....*

**IV) Electronic transport**
*fundamental studies, impact of functionalization*

**V) Nanodevices**
*spin transport devices*



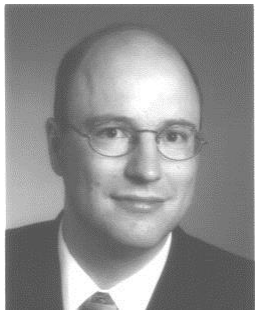

**→ close collaboration of partnerts from surface science and low temperature physics**

**→ bridge the gap between atomic and mesoscopic scales**

# TAILSPIN team

- Kees Flipse, University of Eindhoven

*low temperature spin-**STM** (high magnetic fields)*



- Ulrich Starke, MPI Stuttgart

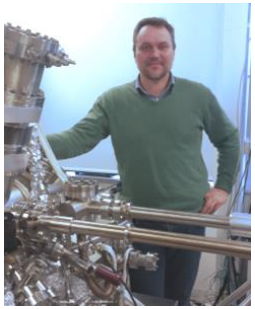
*angle resolved photoemisson (spin-**ARPES**)*

- Alexei Zakharov, Max lab Lund

*low energy electron microscpopy (**LEEM**)*

- Bart van Wees, University of Groningen

*low temperature, **spin resolved transport** & devices*



- Christoph Tegenkamp, University of Hannover

*surface transport (**4-tip STM/SEM**), growth*

# Work packages (WP) for TAILSPIN

| | Topics | Partner | 1-6 | 7-12 | 13-18 | 19-24 | 25-30 | 31-36 |
|---|---|---|---|---|---|---|---|---|
| WP1 | Fabrication of sidewall GNRs | 1,4 | | | | | | |
| | Improvement: kinetics, edge states | 2,3 | | | | | | |
| WP2 | Functionalization: adsorption, defects, intercalation | 2,4 | | | | | | |
| WP3 | Local spin polarization: spin-STS | 2 | | | | | | |
| | Band structure: PEEM, ARPES, spin-ARPES | 1,3,4 | | | | | | |
| | Excitations: RIXS | 2** | | | | | | |
| WP4 | Nanoscopic transport | 1 | | | | | | |
| | Spin polarized and magneto transport | 2***,5 | | | | | | |
| WP5 | 2-terminal (gated) nanodevices on pristine GNRs, four terminal devices | 5 | | | | | | |
| | Fully GNR based two-terminal spin valve devices | 5 | | | | | | |

*Partners:*

1: Tegenkamp, Hannover
(4-tip STM/SEM)

2: Flipse, Eindhoven
(STM/STS)

3: Zakharov, Lund
(LEEM/PEEM)

4: Starke, Stuttgart
(ARPES)

5: van Wees, Groningen
(cryogenic transport)

**: RIXS in collaboration with Jean-Pascual Rueff, SOLEIL

***: magneto Hall in coll. with Ulrich Zeitler, Nijmegen

# Complementarity and synergies with the Flagship CP

## WP1 – Materials

- expertise in growth of graphene on SiC (Seyller, Yamikova,etc.)
- growth of nanostructures not in scope of WP1

## WP3 – Fundamentals

- theoretical studies on defects , edges, interfaces, intercalates,...

## WP6 – Spintronic

- focusses „only“ on 2D graphene
- our nanostructures will complement  the 2D efforts