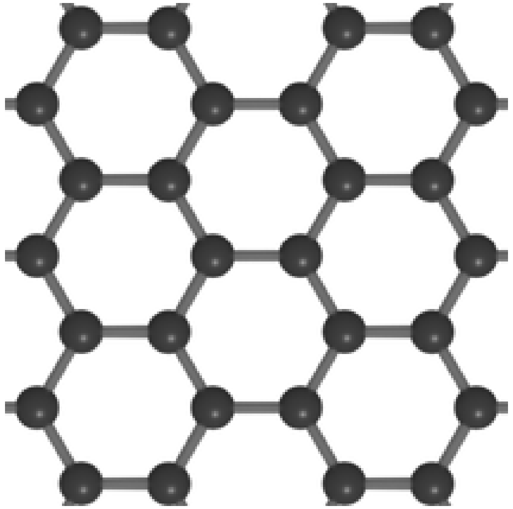
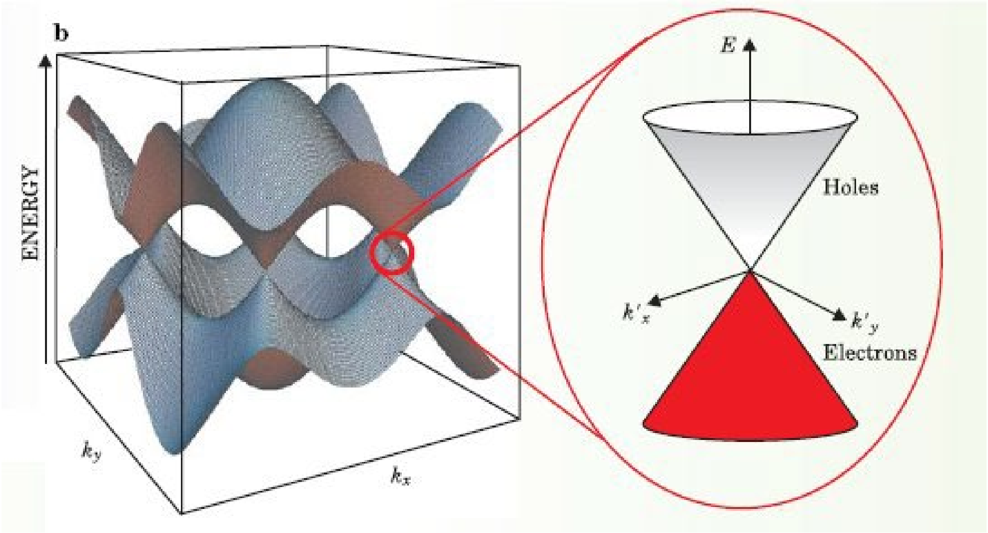
Ballistic transport spectroscopy of spin-orbit-coupled bands in monolayer graphene on WSe2

Nat Commun **14**, 6124 (2023)

Journal Club - 06 June 2025

Graphene



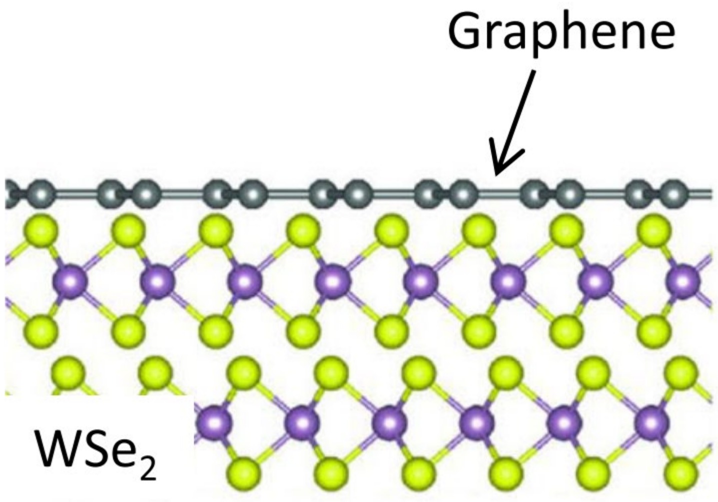


- Hexagonal Brillouin Zone
- Dirac Cones at K points
- Semimetal
- Negligible Spin Orbit Interaction.

Graphene

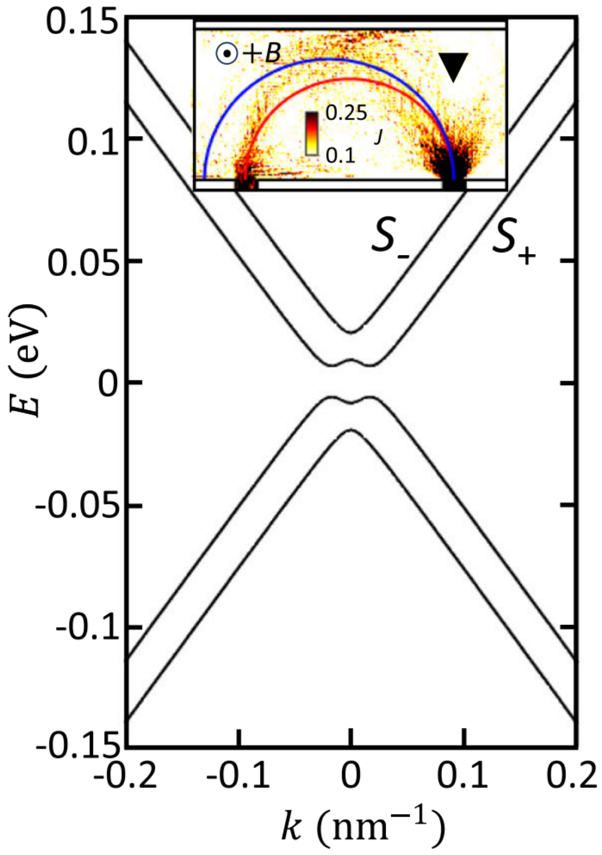
Something with High SOI

Device structure

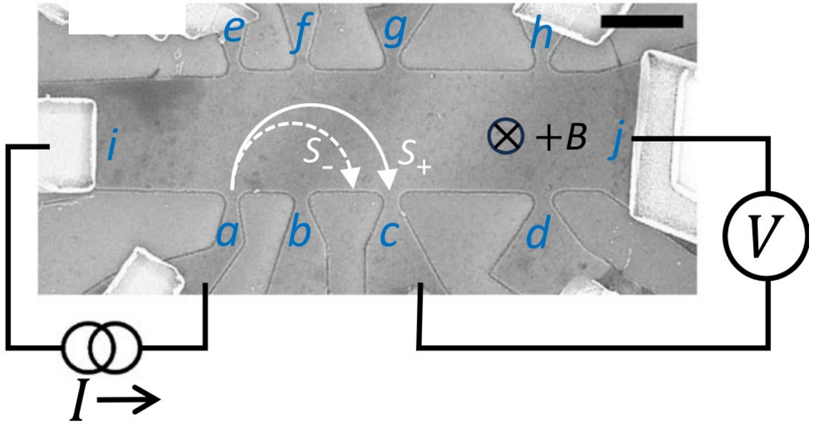


- Transition Metal Dichalcogenide.
- Higher SOI
- Optically active Semiconductors
- Have Valley degree of freedom

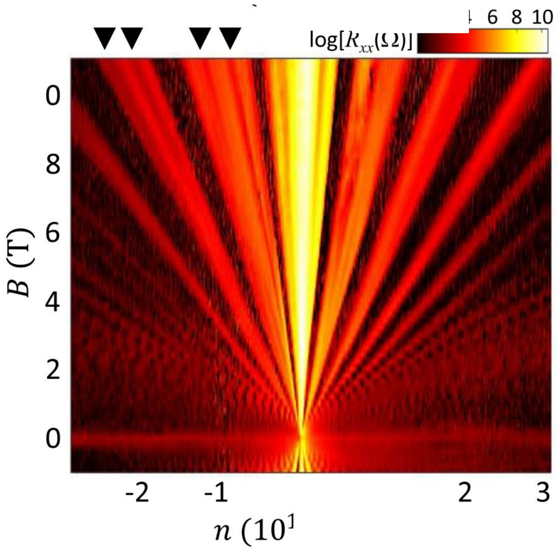
$$H = H_0 + \Delta\sigma_z + \lambda\tau_z s_z + \lambda_R\left(\tau_z\sigma_x s_y - \sigma_y s_x\right)$$

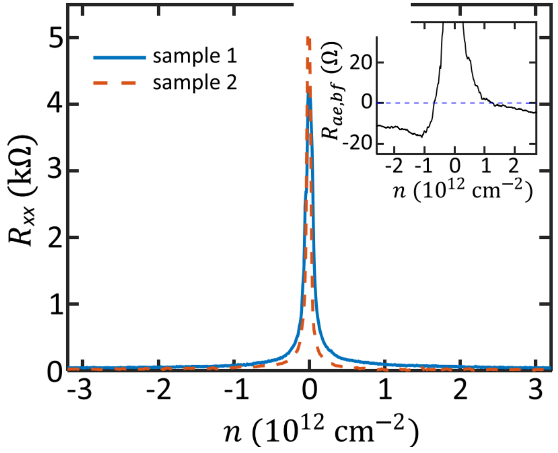


Device structure for Focusing experiment



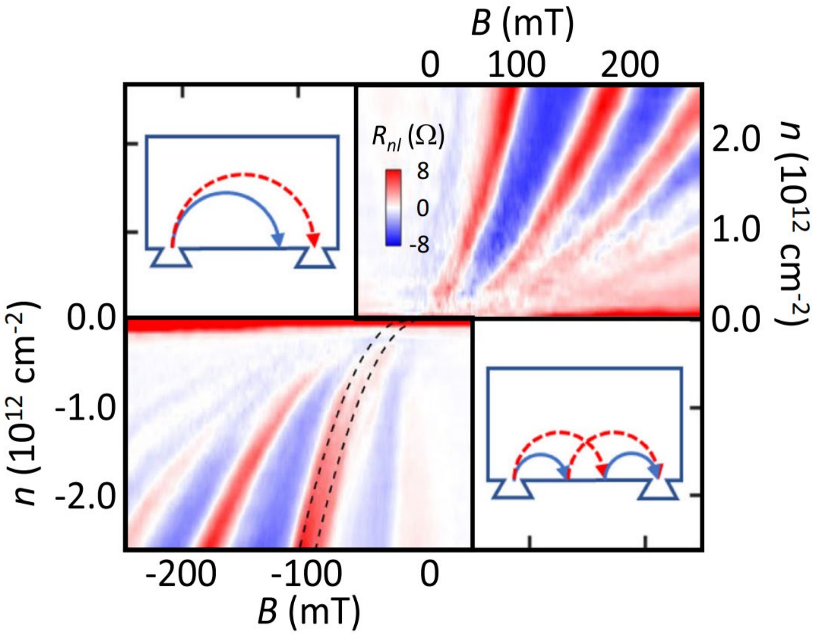
- Better hole conductance properties
- Carrier mobility of 200,000 ~ 400,000 cm2 V-1s-1
- Sharp longitudinal resistance peak





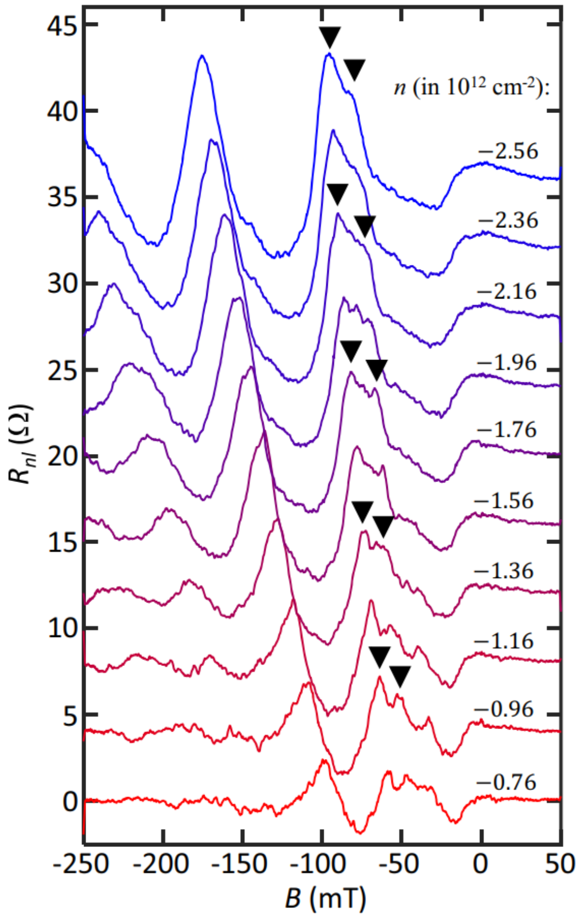
$$B_j = \pm \frac{2j\hbar}{|e|L} k_F$$

Transverse magnetic focusing spectra

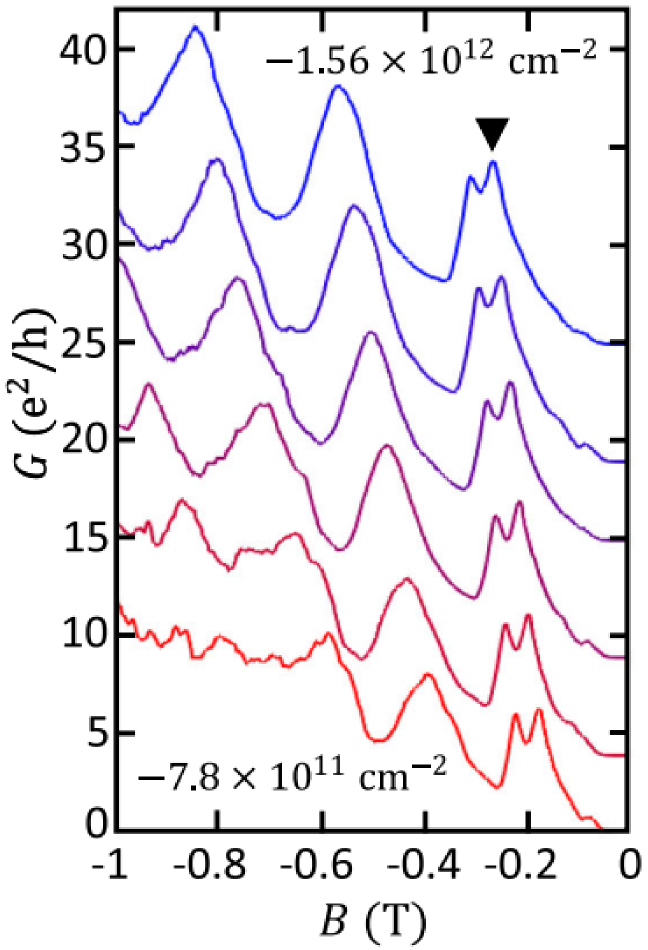


The first peak is split

$$\lambda_{SOC} \equiv \sqrt{\lambda^2 + \lambda_R^{\ 2}} = 13.9 \quad \text{meV}$$

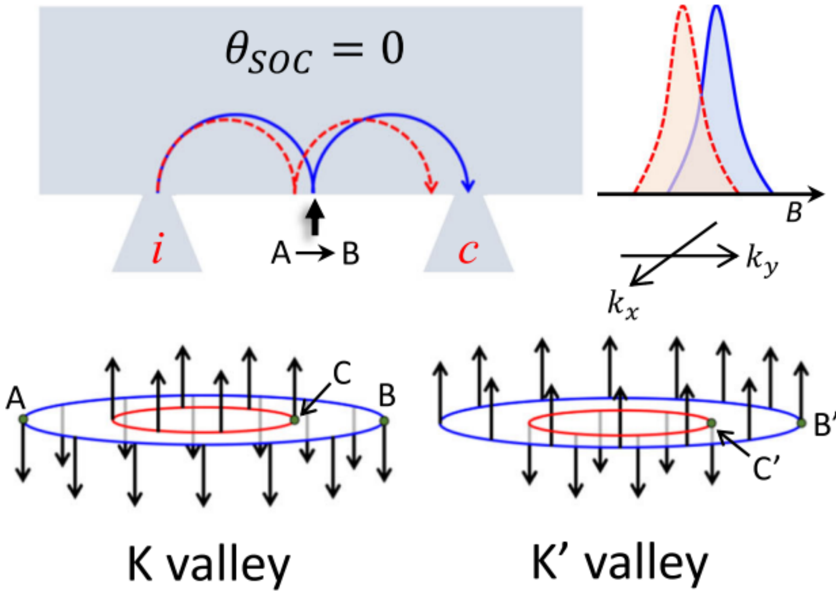


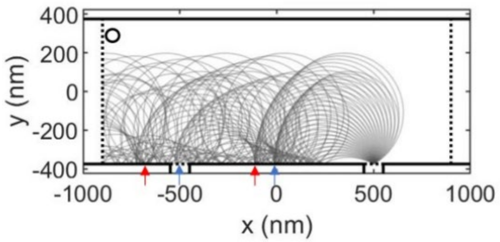
Measured Data

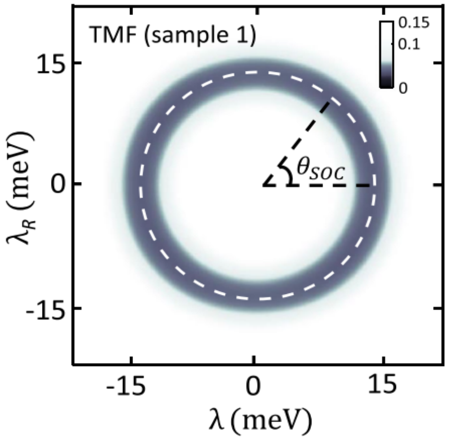


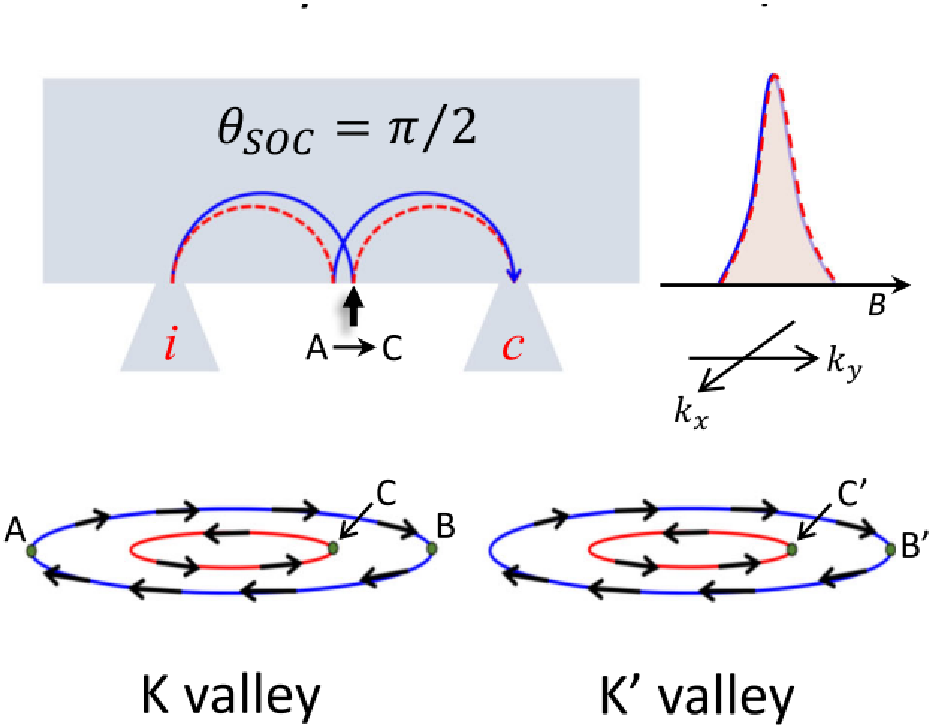
Simulated Data

Analysis of the second focusing peak



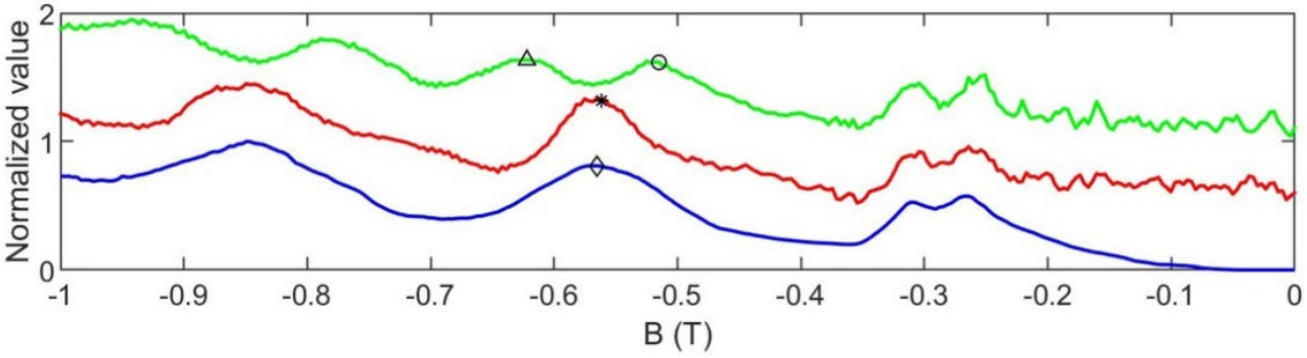




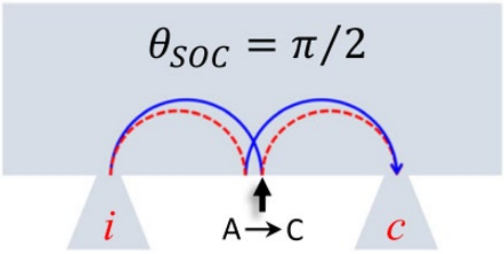


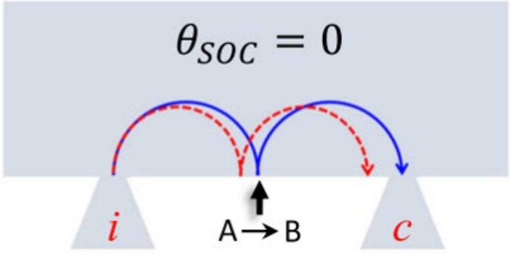
$$\langle \delta B^2 \rangle \equiv \sum[(\Delta B_+/B_0)^2 + (\Delta B_-/B_0)^2]/N$$

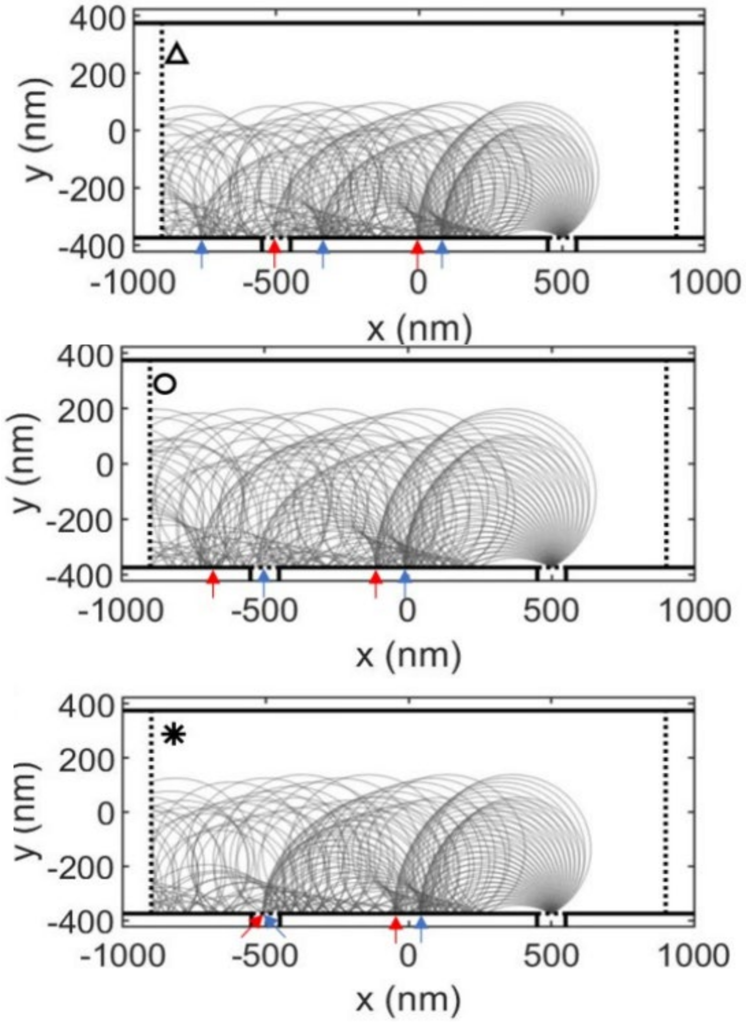
Analysis of the second focusing peak



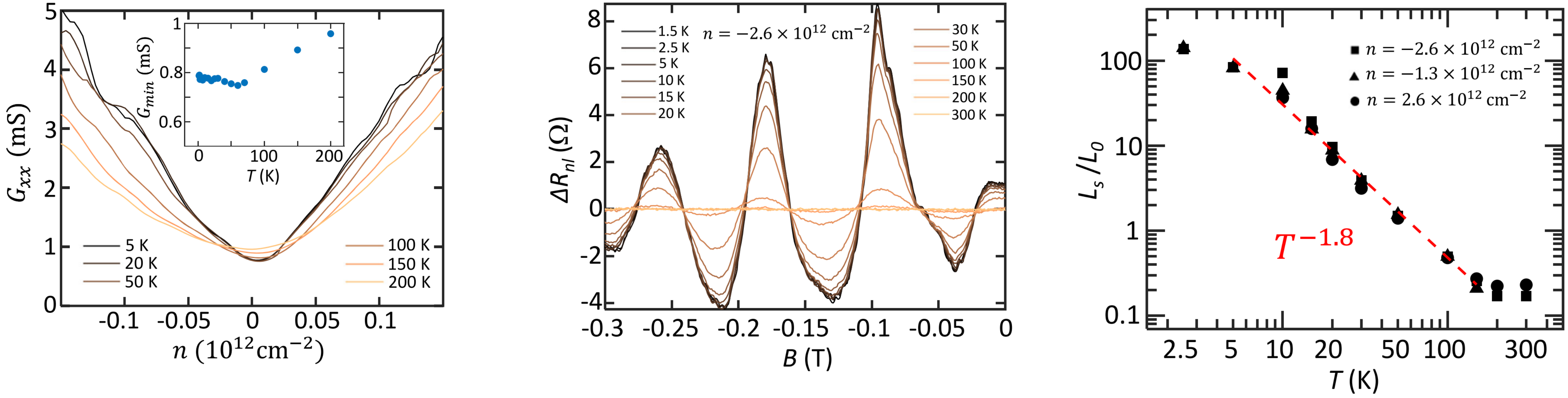
simulation for the second focusing peak







Temperature Dependent Measurements

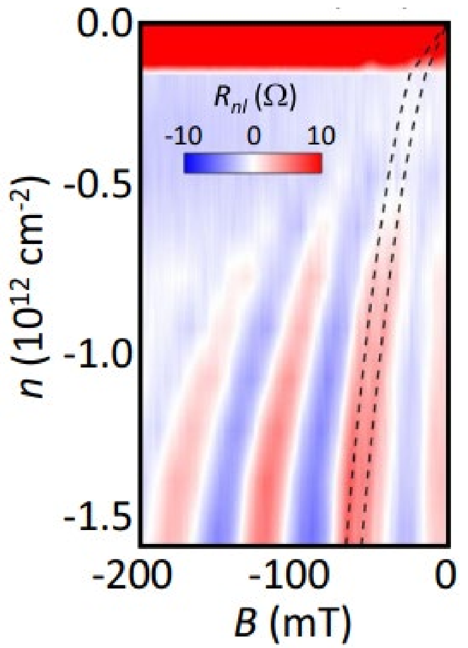


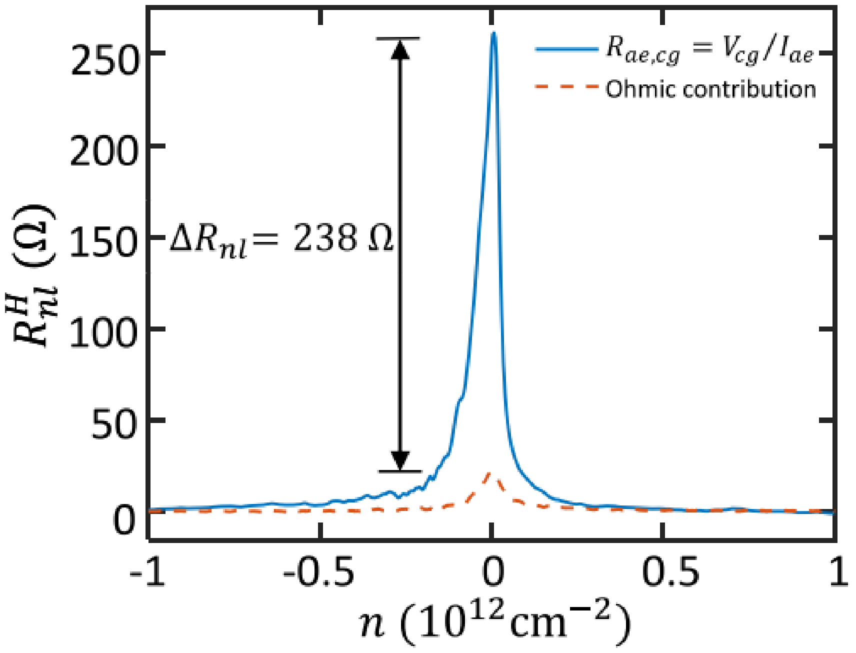
T^{-1} Dependence for electron-phonon scattering

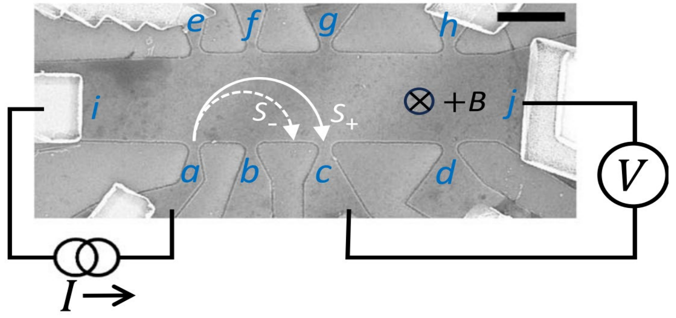
T^{-2} Dependence for electron-electron scattering

e-e scattering is dominant, But it is also slightly suppressed

Spin Hall effect at Lower Carrier Density



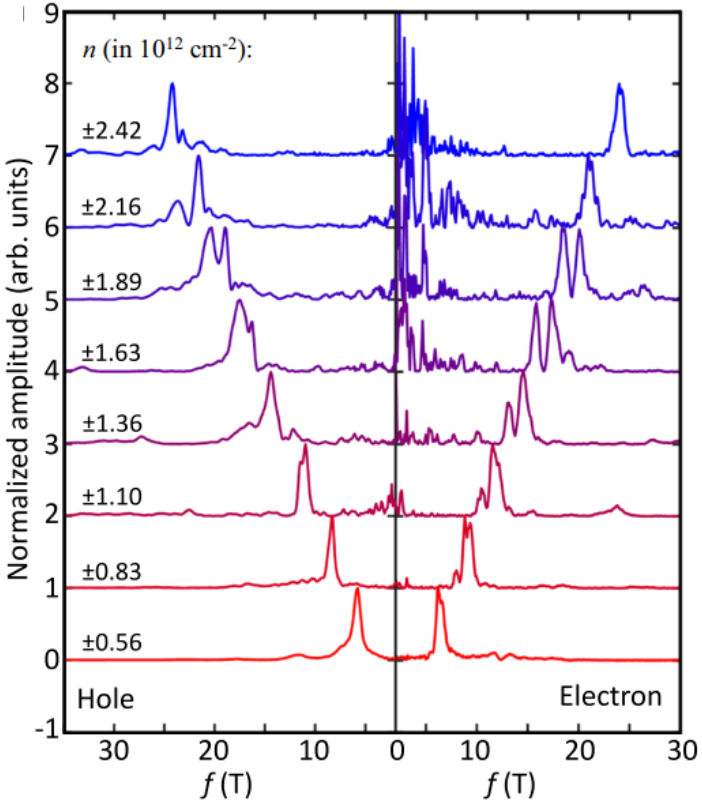


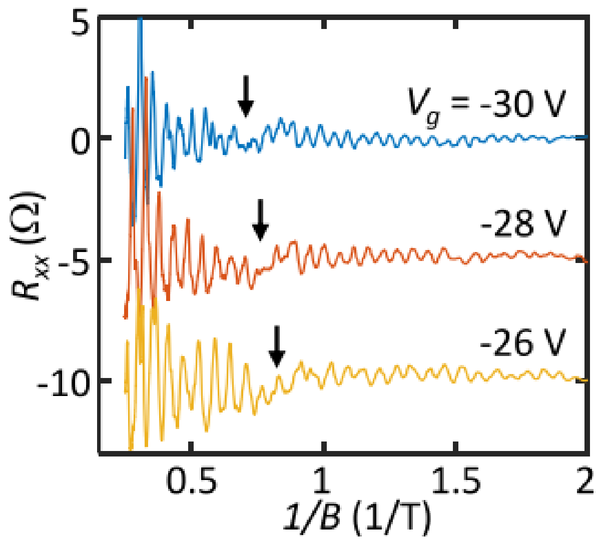


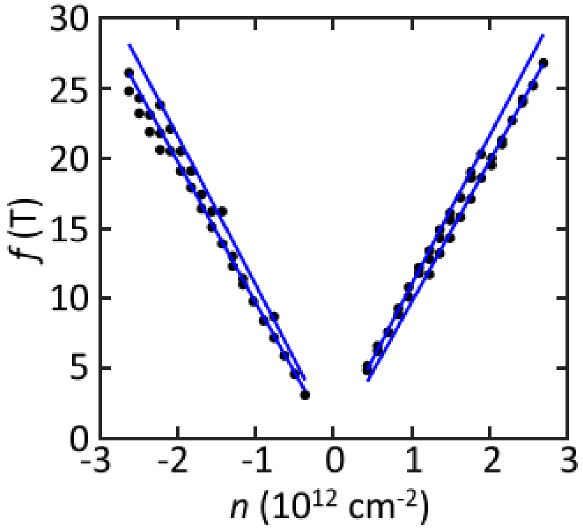
$$R^H_{nl} = R_{ae,cg}$$

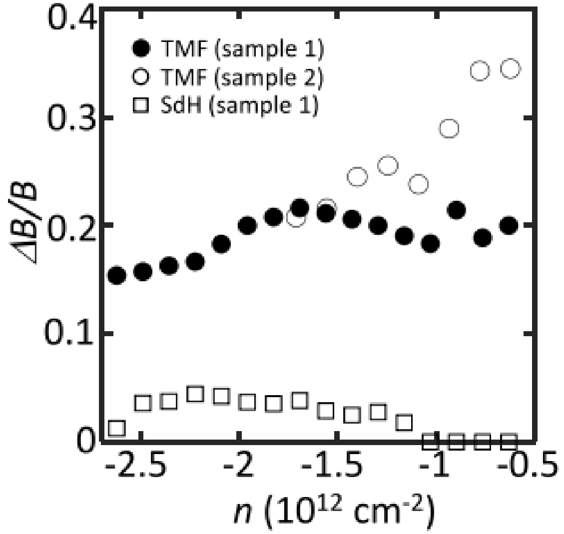
$$R_{ae,bf}\left(\equiv V_{bf}/I_{ae}\right)$$

Comparison with Shubnikov–de Haas (SdH) oscillations









$\lambda_{SOC} = 3.4 \pm 0.7$ meV

Conclusions

- **Ballistic electron motion** and **spin-orbit coupled (SOC) band splitting** were demonstrated in graphene on WSe_2 via Transverse Magnetic Focusing (TMF).
- The **first TMF peak showed splitting**, revealing a **strong SOC strength of ~13 meV.**
- The **absence of splitting in the second TMF peak** indicates a **dominant Rashba SOC**, due to inter-band scattering at the edge.
- **Electron-electron scattering** showed a **possible suppression.**
- **Shubnikov-de Haas (SdH) oscillations** showed **weaker SOC (~3.4 meV)**, suggesting **different electron dynamics** and a need for new theory.
- This establishes graphene-TMDC heterostructures as a **promising platform for spin-orbitronics**

Thankyou all