INVESTIGATION OF DIRAC AND 2D MATERIAL SURFACES WITH HELIUM ATOM SCATTERING

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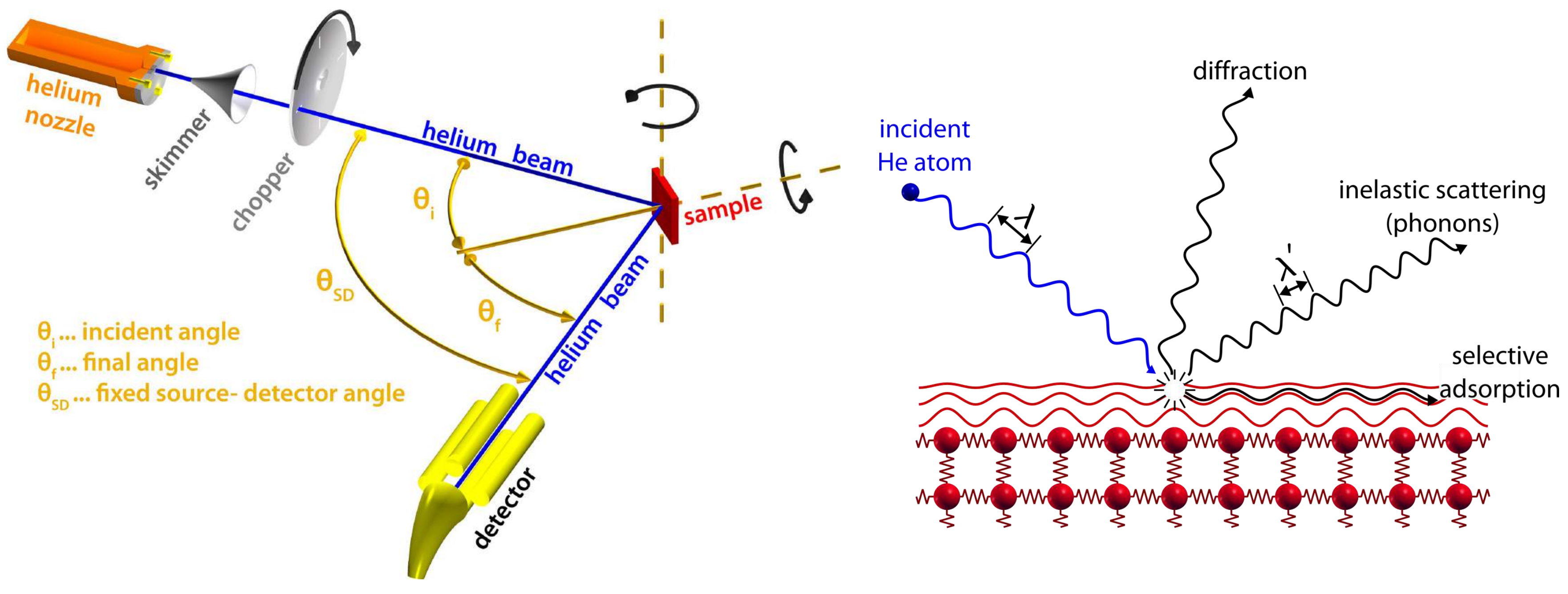
Why use Helium Atoms?

- Helium atom scattering (HAS) is a powerful technique to analyse the surface properties
- Helium atoms are scattered by the electron density 2-3 Å above the first atomic layer due to the Pauli repulsion → non-destructive, strictly surface sensitive technique
- Typical energy range of helium atoms: 5-200 meV
- Helium atoms are neutral and chemically inert therefore insensitive to surface charges → investigation of insulting materials
- As a noble gas helium is chemically inert → completely inert investigation

Experimental Setup

Helium atom scattering apparatus and scattering geometry

- Helium beam is generated in the source chamber by supersonic expansion through a nozzle
- Helium beam is scattered in the main chamber at UHV-conditions and detected in a quadrupole mass-spectrometer
- Chopper is added into the beam for energy dependent measurements (TOF)
- Fixed source-detector angle $\theta_{SD} = \theta_i + \theta_f = 91.5°$



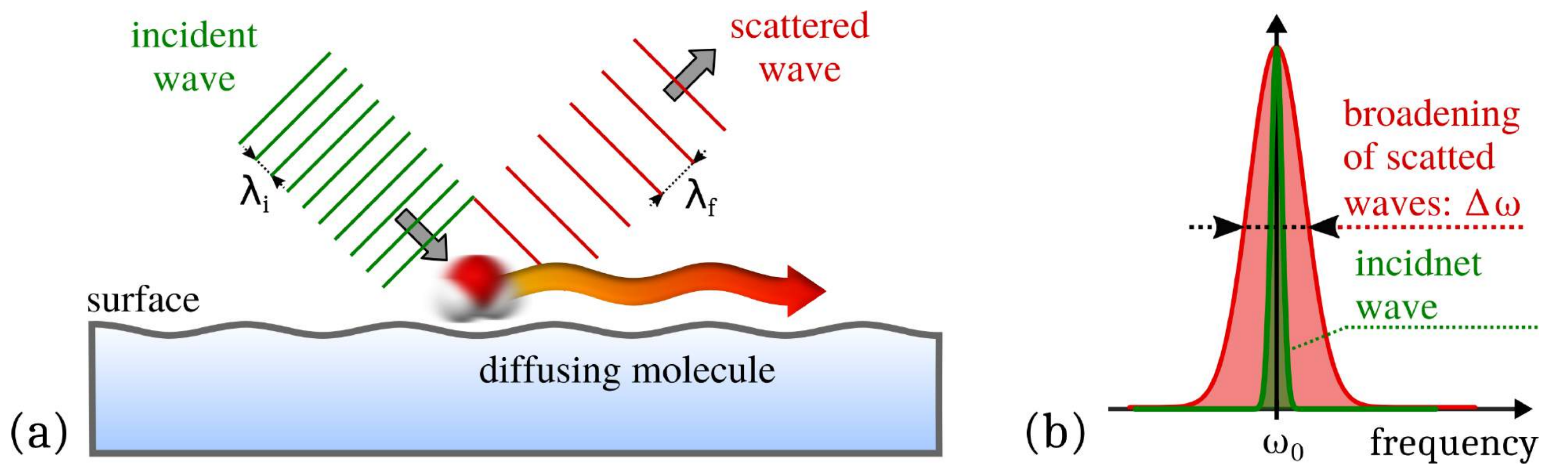
Interaction processes at the surface

- Elastic diffraction:
  no energy exchange between the helium atoms and surface
- Inelastic scattering:
  incident helium atom looses or gains energy via creating or annihilating a phonon
- Selective adsorption resonance (SAR):
  helium atom is temporarily trapped in a bound state of the interaction potential

Surface Diffusion in Reciprocal Space

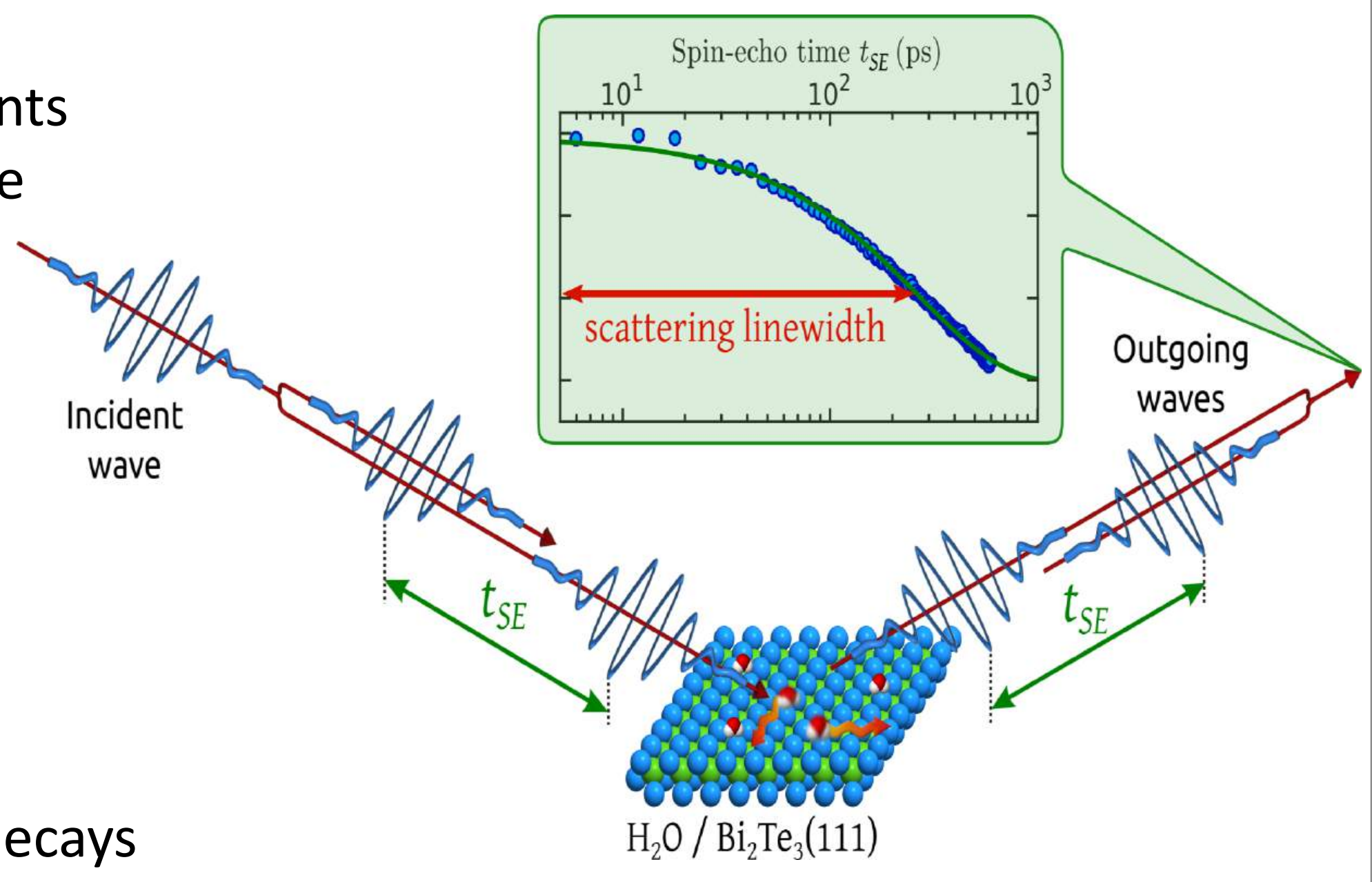
Quasi-elastic helium atom scattering

- Only experimental method to continually monitor mobile species on both Å length and ps timescales [1]
- Helium atoms scattered from moving molecules on the surface can exchange energy with the surface atoms resulting in in a broadening around the elastically scattered peak (analogous to Doppler broadening) → quasi-elastic broadening of elastic peak [1]
- Extent and rate of broadening depends on rate and mechanism of diffusion



Helium spin-echo (HeSE) spectroscopy

- Using nuclear-spin polarisation of He^3 to measure coherence [1]
- Incident wave is split into two components which arrive with a time spread t_{SE} at the surface
- Coherence of two components after scattering is measured
- Scattered waves differ as a result of changes on the surface during t_{SE} → loss of correlation [1]
- Final outcome: Intermediate scattering function (ISF) $I(\Delta\boldsymbol{K}, t)$
- For simple models of diffusion, the ISF decays exponentially [1]



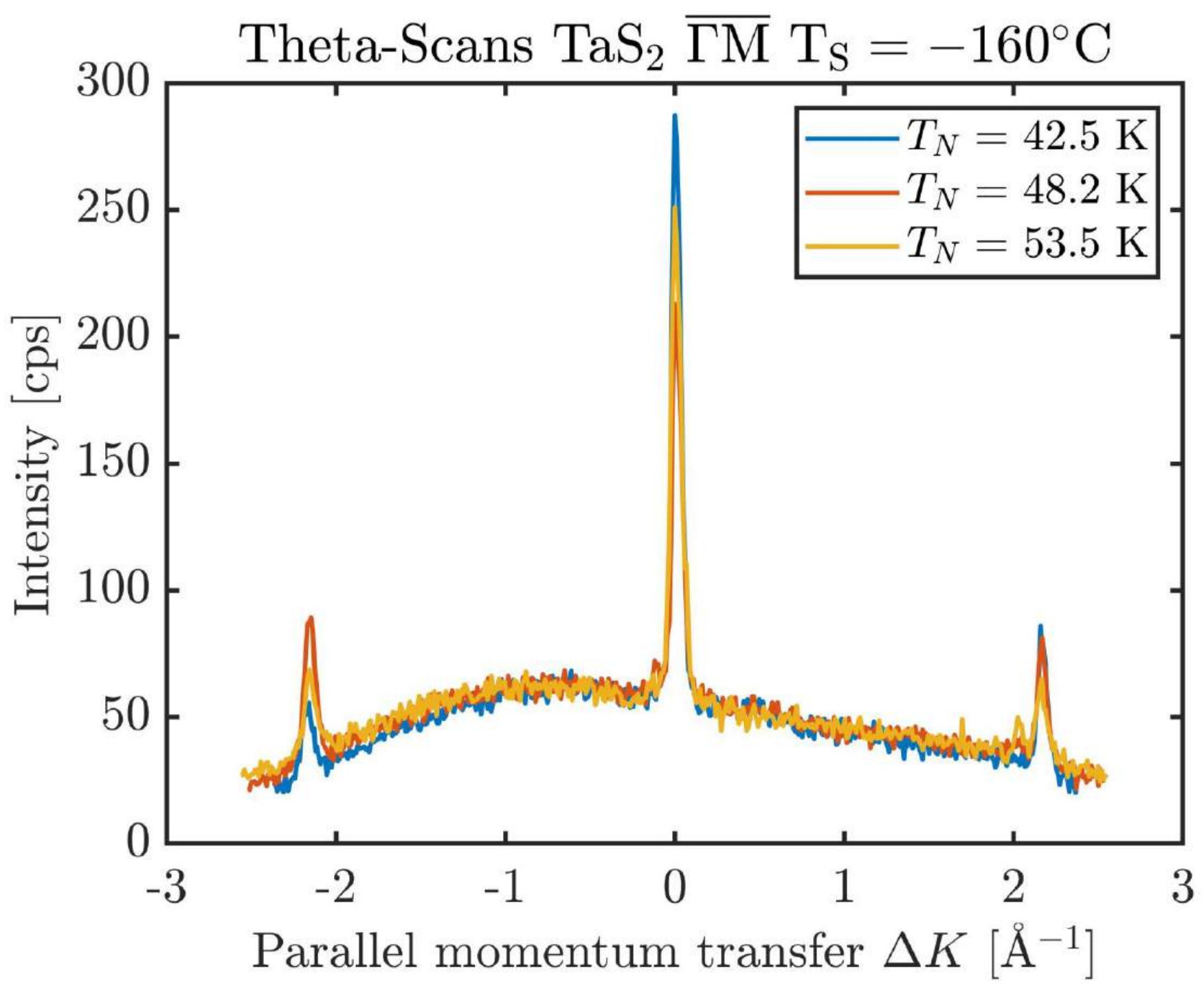
Charge Density Waves in TaS$_2$

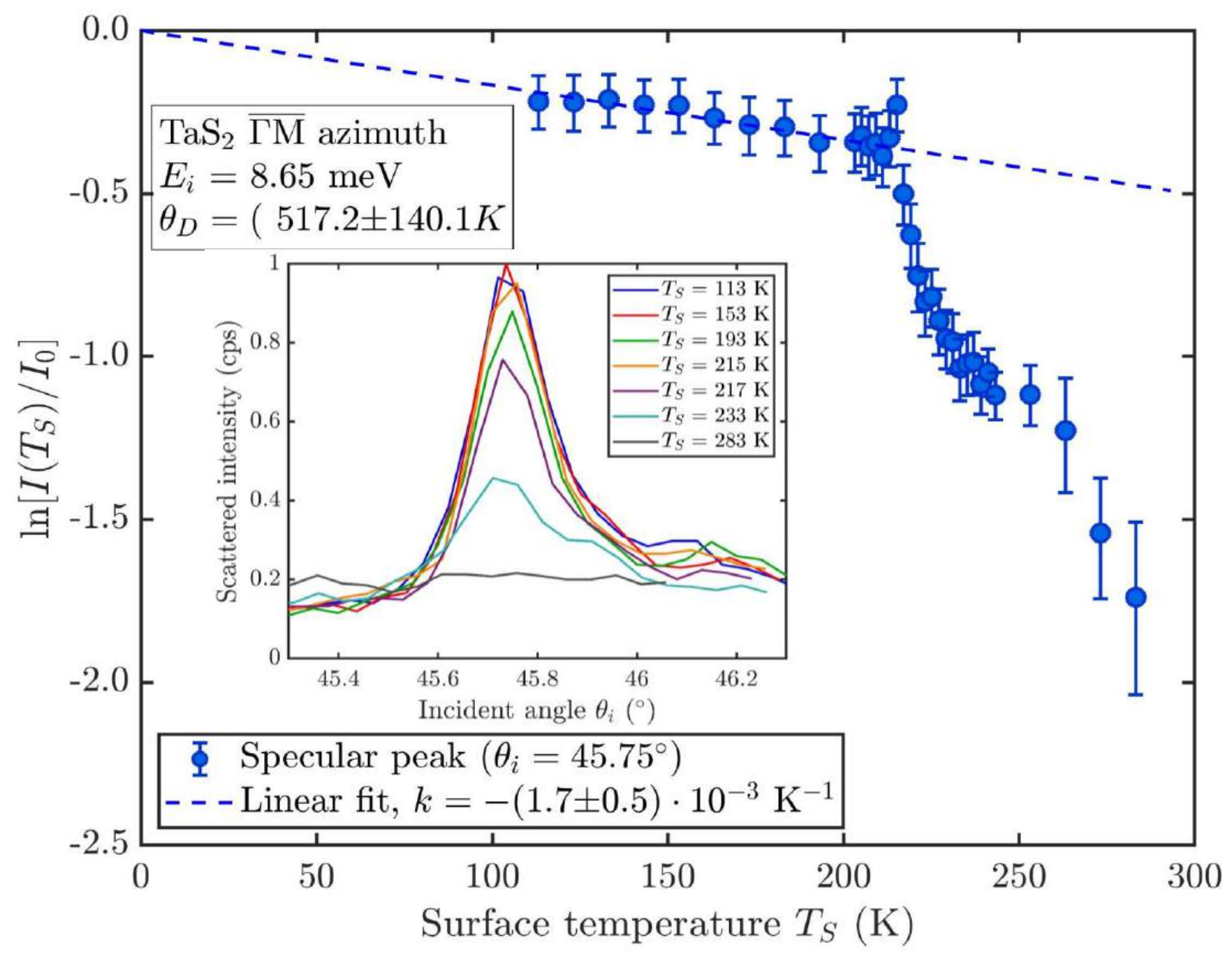
Monitoring the phase transition in TaS$_2$

- TaS$_2$ exhibits multiple charge density wave (CDW) states [2]
- Transition from a nearly-commensurate (NC-CDW) phase to a commensurate (C-CDW) charge density wave phase at roughly T = 220 K [3]
- Debye-Waller measurement: elastic peak intensity plotted against the surface temperature

$$I(T_S) = I_0 \cdot e^{-2W(T_S)}$$

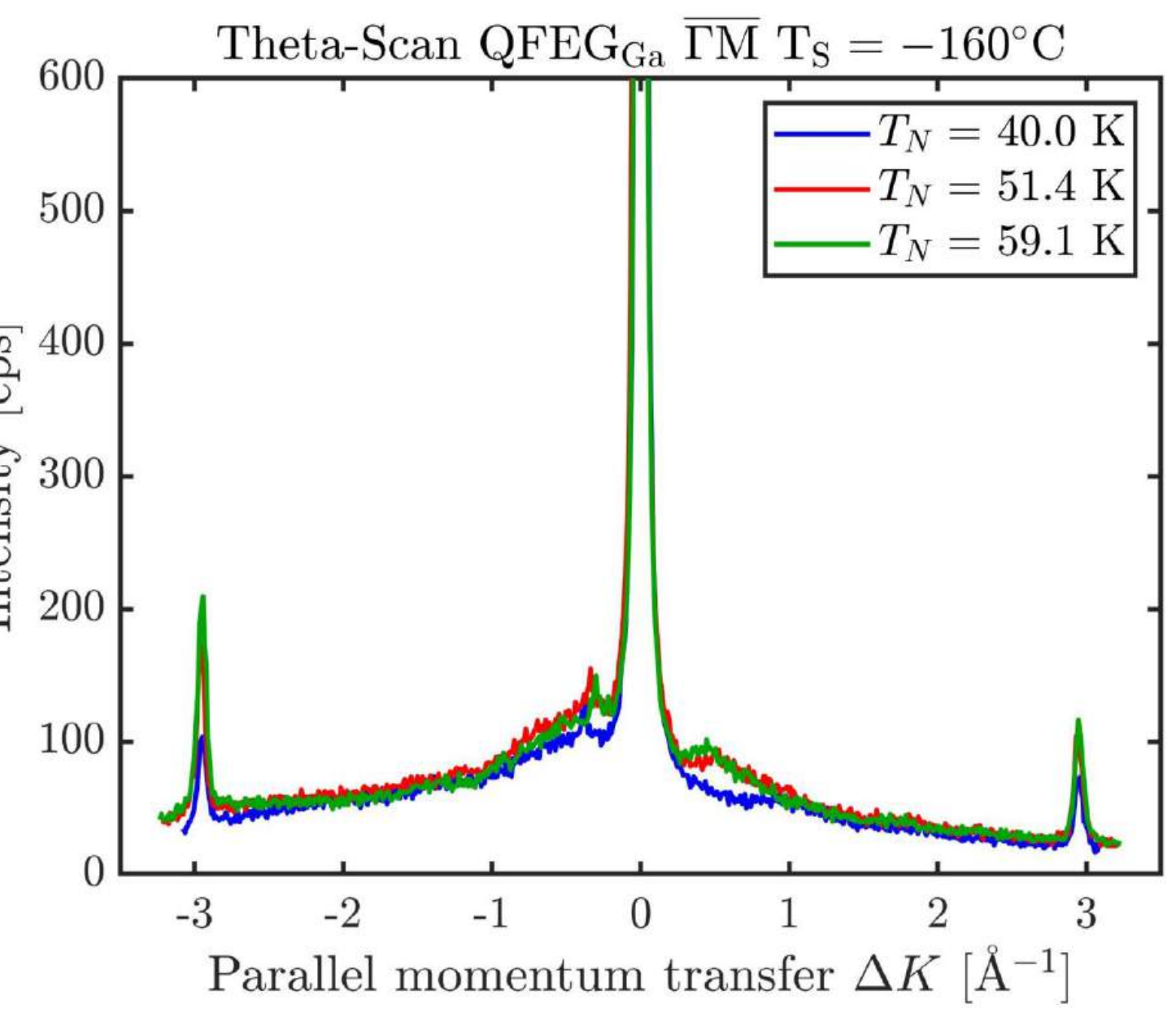
  with $W(T_S)$ being the Debye-Waller (DW) exponent [3]
- Debye-Waller exponent contains contributions of all phonon modes → measure for the electron-phonon coupling constant [4]
- Increased sample temperature leads to more vibrational modes → decreasing specular intensity [4]
- Very sharp, stepwise onset in the intensity at the transition temperature
  → discontinuous, first-order transition
  → rapid increase in electron-phonon coupling [3]



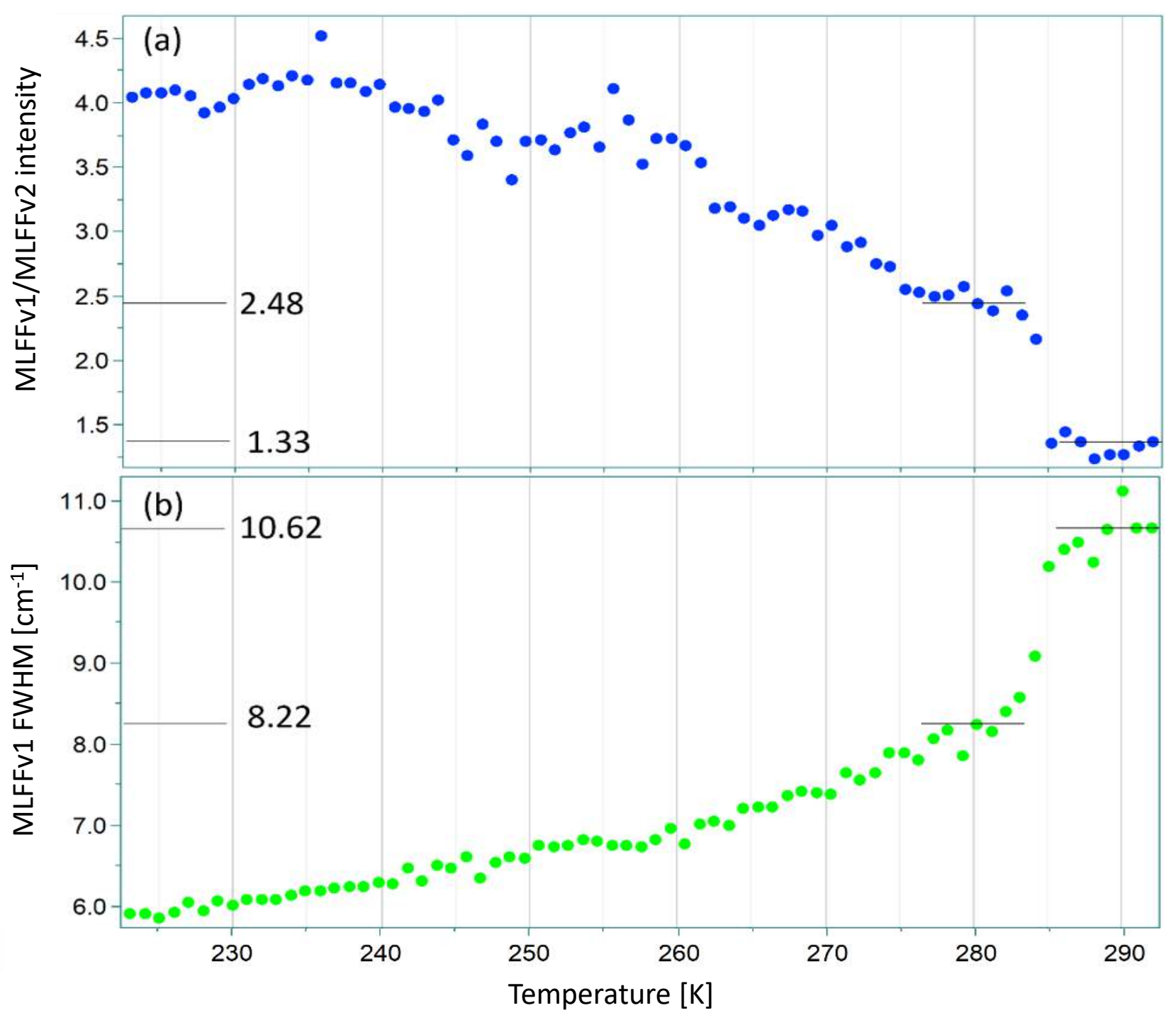


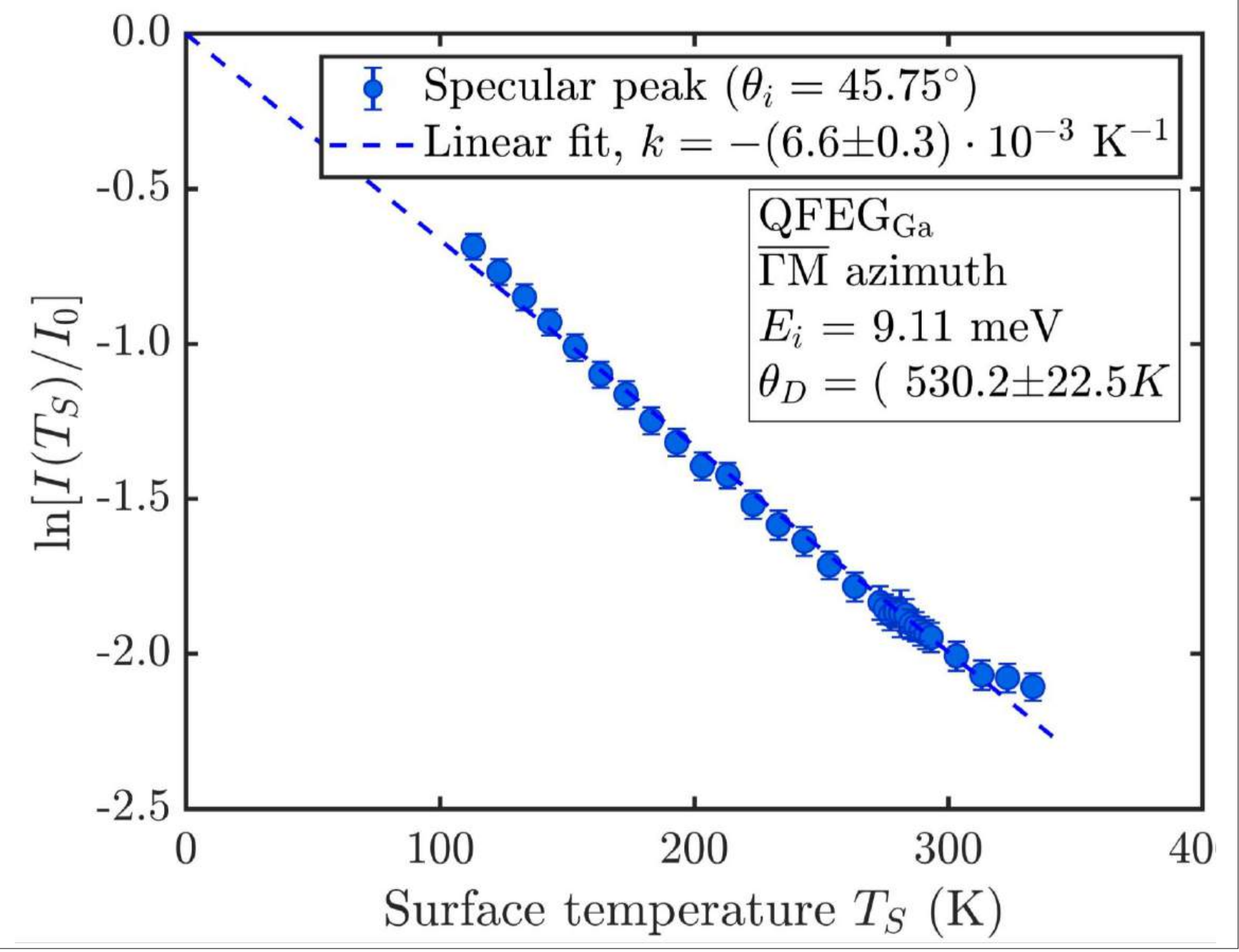
2D-Polar Metals

Quasi-Freestanding Epitaxial Graphene w/ Gallium intercalation



- Using confinement heteroepitaxy (Chet) an atomically-thin (2D) metal can be intercalated [5] at an epitaxial graphene (EG)/ silicon carbide(SiC) interface [5]
- The process of intercalation modifies the physical properties of the metal (e.g. enhanced conductivity, unique Raman features) [5,6]
- Nice and clear diffraction pattern from graphene in helium scattering
- DW-measurement at specular peak:
  → θ_D= 530 K
  → no transition in e-phonon coupling observable





Outlook

- TaS$_2$: theoretical calculations (CC-calculations) to obtain information about the surface corrugation and the surface interaction potential
- QFEG$_{Ga}$: measuring disorder-to order transition at 285 K (observed in Raman spectroscopy); measurements of other QFEG-materials
- surface diffusion measurements of various molecules on different surfaces (e.g. water on hexagonal boron nitride (h-BN))

References

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