Quantum oscillations under the Magnetic breakdown regime in Nodal line semimetals ZrSiS and HfSiS

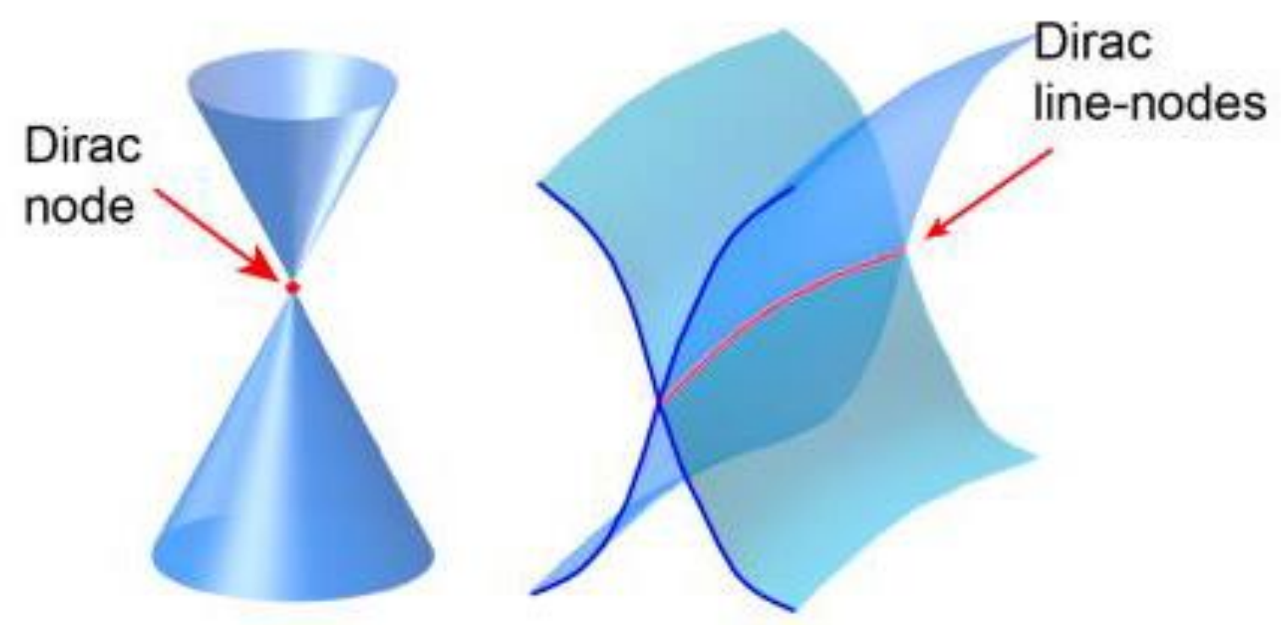
[1]F. Orbanić, [1]M. Novak, [1]B. Gudac [2]A. McCollam, [2]L. Tang, [1]I. Kokanović

[1]Department of Physics, Faculty of Science, University of Zagreb, Croatia
[2]High Field Magnet Laboratory, Radbound University, Nijmegen, the Netherlands

E-mail: forbanic@phy.hr

SCES '19 OKAYAMA

Nodal line semimetal (NLS)



Downloaded from [1]

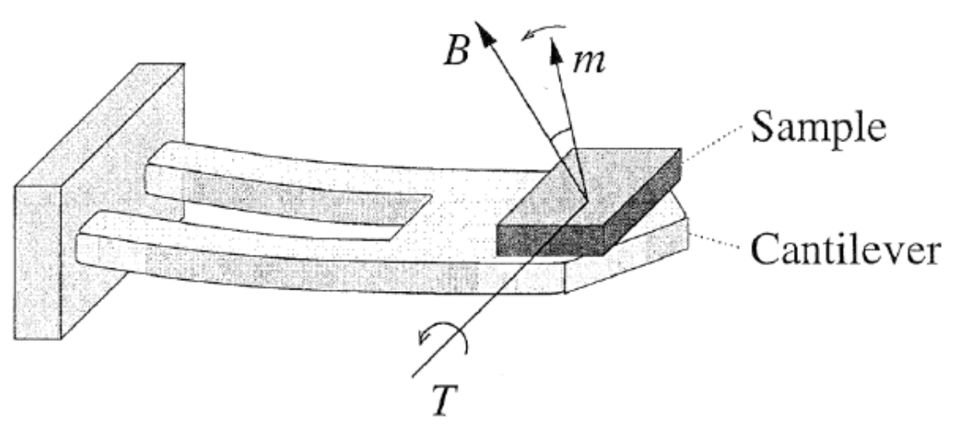
Dirac nodal fermions physics:

- Nontrivial topology
- Peculiar transport properties
- Surface states
- Long-range Coulomb interactions

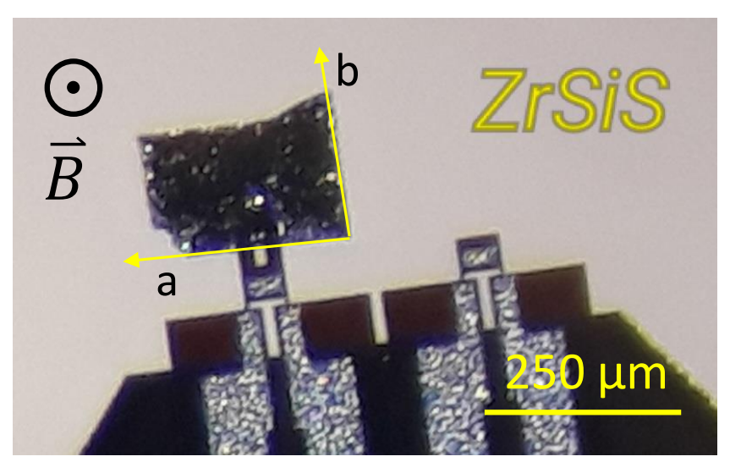
Symmetry protected band degeneracies which form lines.
Linear energy dispersion near these lines → Dirac line nodes.

Measurement technique

Piezoresistive cantilever method was used.



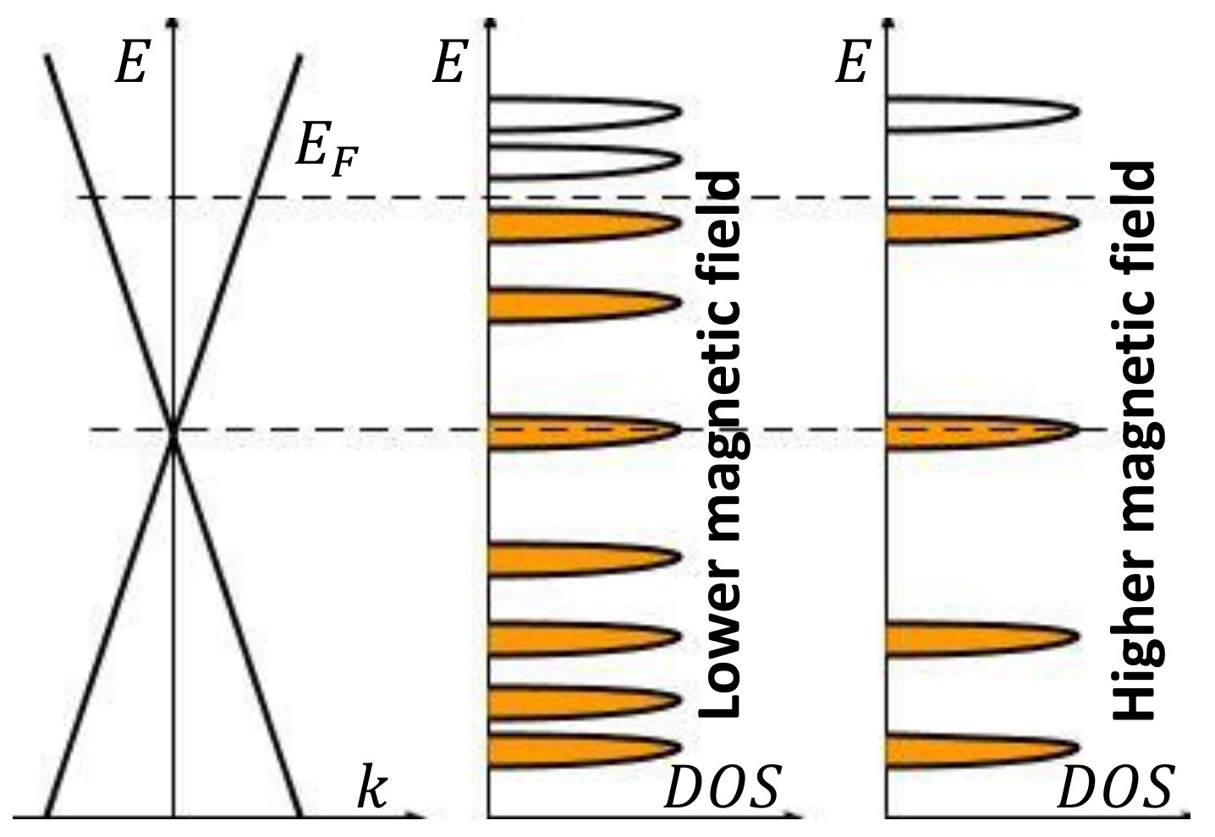
If material posses anisotropy, sample produces torque on lever, $T = \vec{M} \times \vec{B} \propto B^2$.



Sample glued on cantilever.

Torque is measured at 2 K in the fields up to 35 T, for several angles θ between $\vec{B}$ and crystal c-axis.

Quantum oscillations

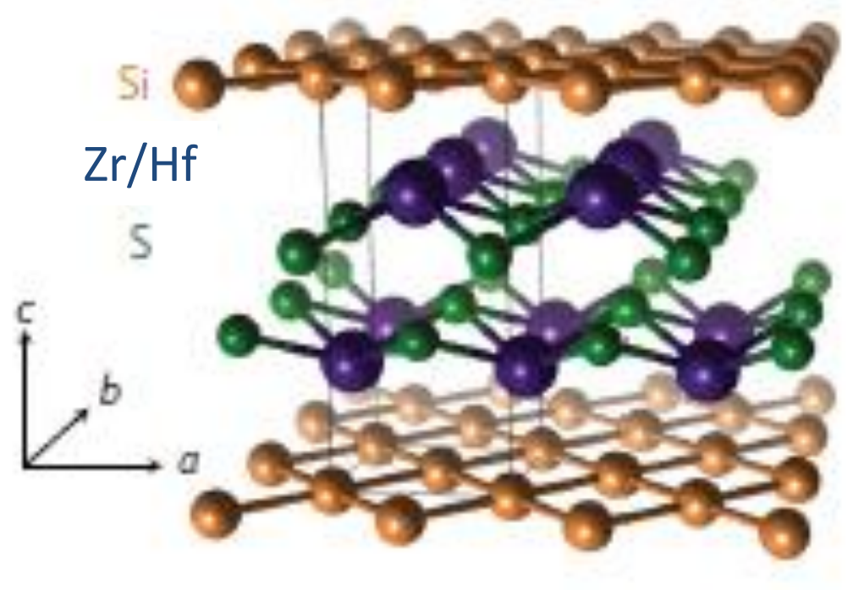


Electrons in a strong magnetic field → Landau levels. Increasing field leads to the periodicaly crossing of Landau levels and E_F → oscillation of physical quantities with 1/B, [3].

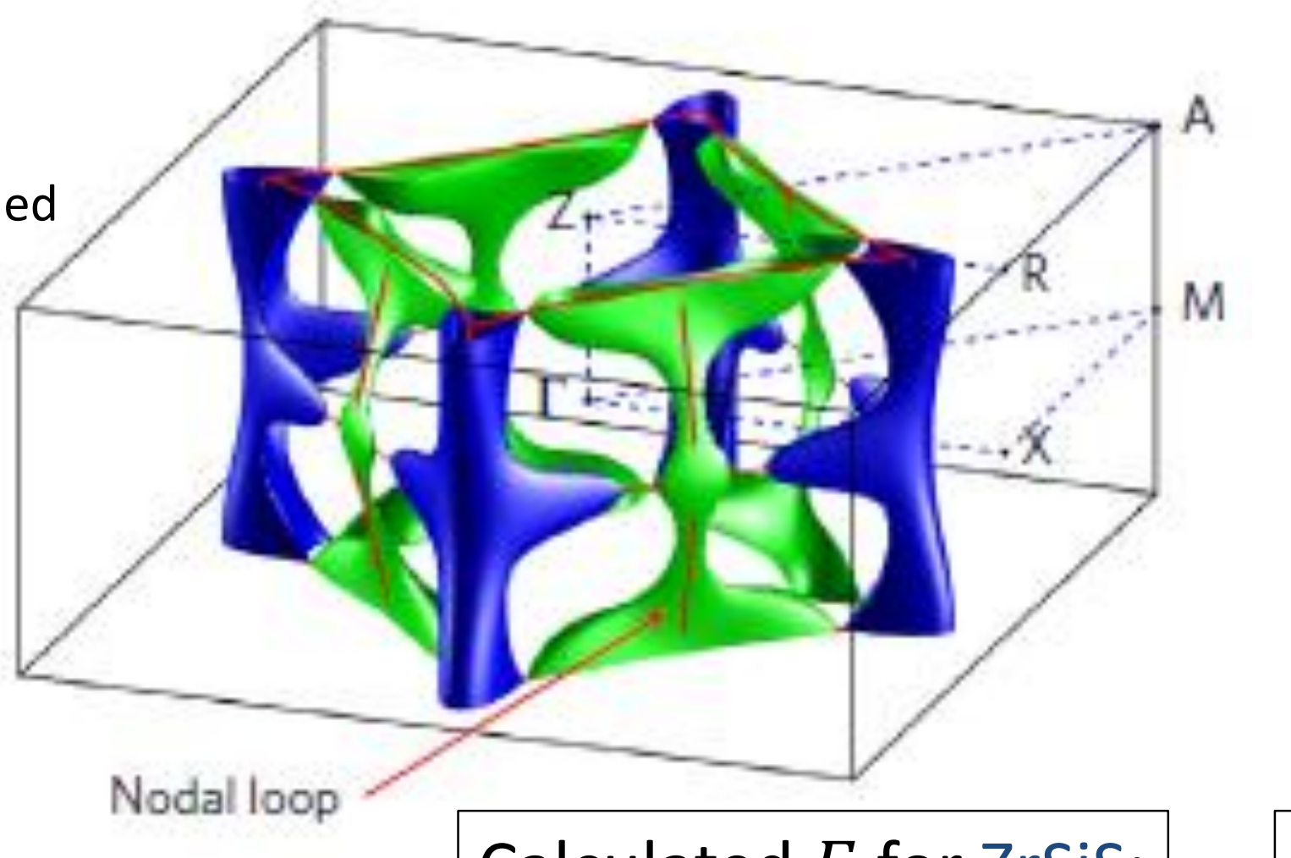
Frequency of oscillations is determined by the extremal cross sections of FS and plane normal to $\vec{B}$ → $F = \frac{\hbar A}{2\pi e} = \frac{\hbar k_F^2}{2e}$

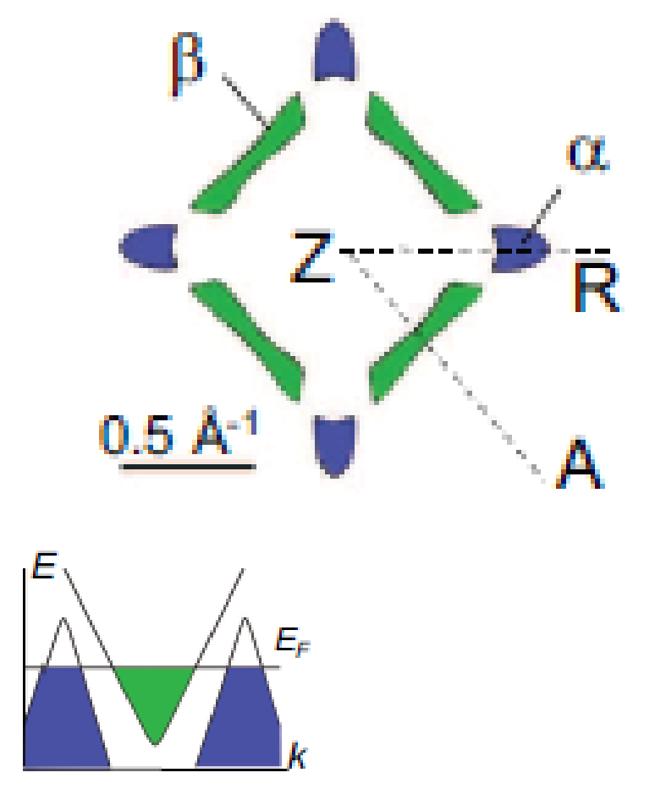
ZrSiS/HfSiS

Tetragonal non-symmorphic (P4/nmm) layered structure and quasi 2D electronic structure.



Downloaded from [2,4]





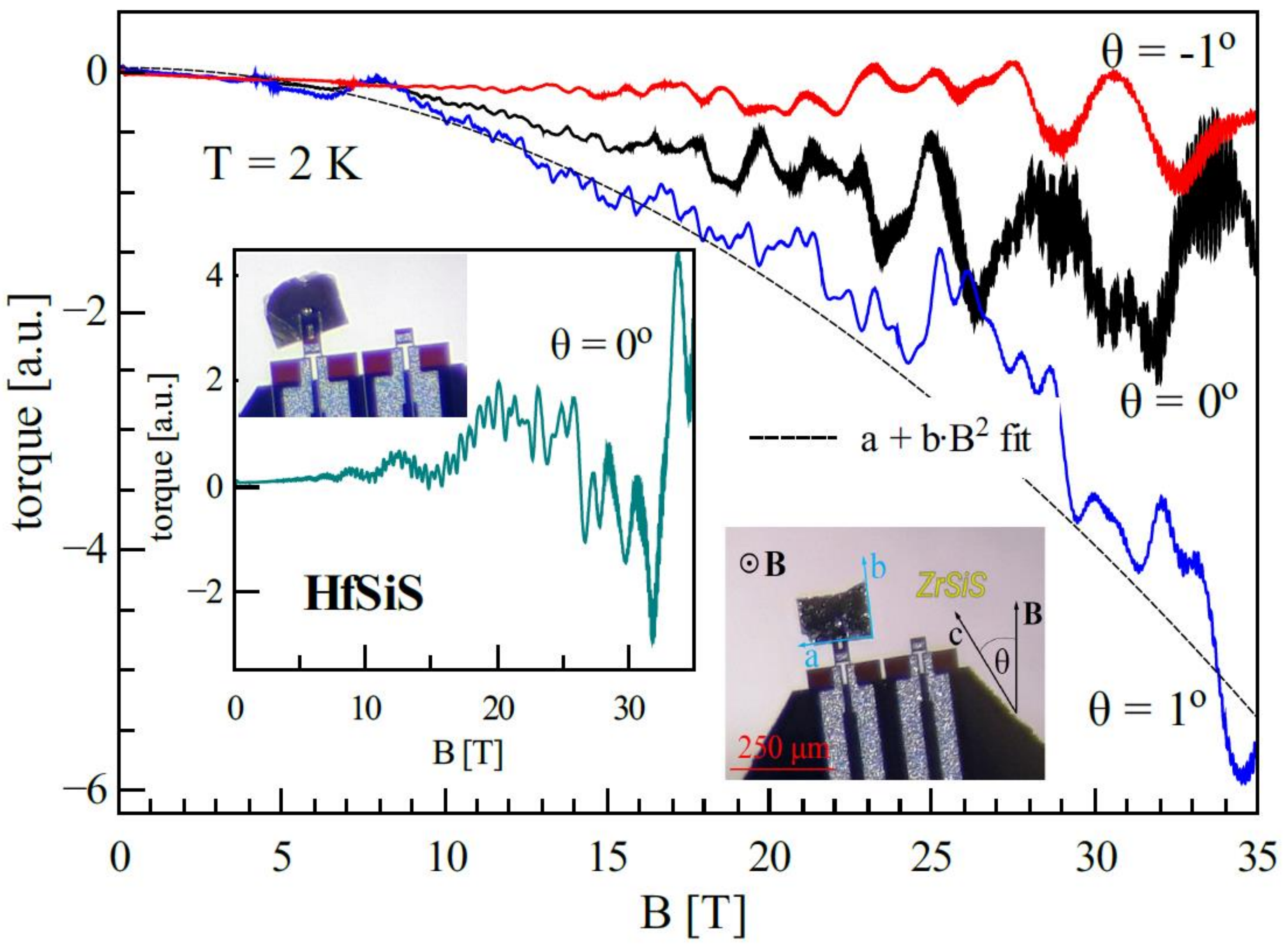
Calculated FS of WSiS consist of electron (β) and hole pockets (α). There is a small energy gap between pockets due to the spin orbit interaction.

Calculated F for ZrSiS:
$\alpha = 235$ T,
$\beta = 596$ T.

ref [2,4]

Calculated F for HfSiS:
$\alpha = 294$ T,
$\beta = 631$ T.

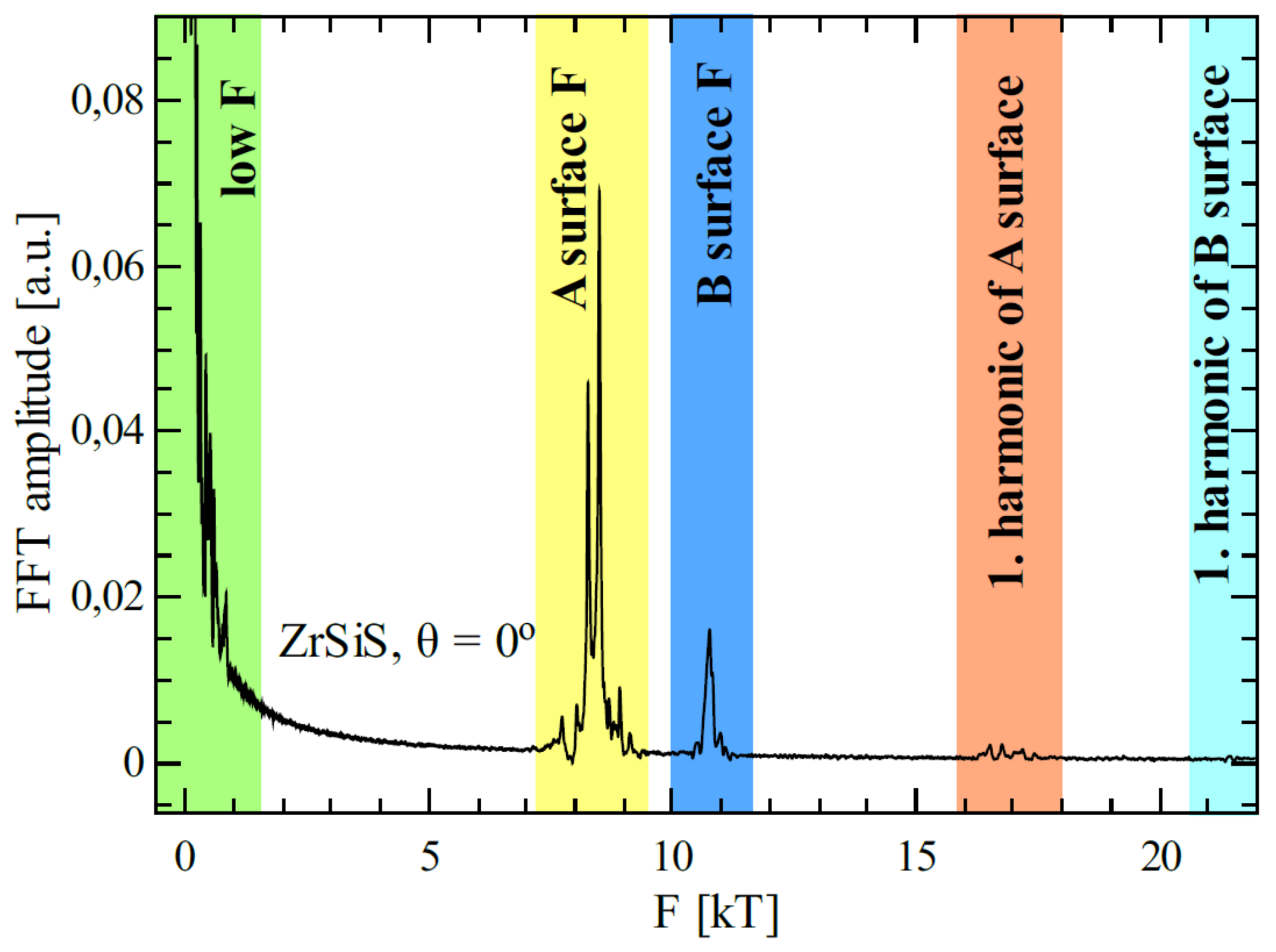
Torque measurements



Torque signal consists of B^2 dependent background and quantum oscillation contributions superposed.

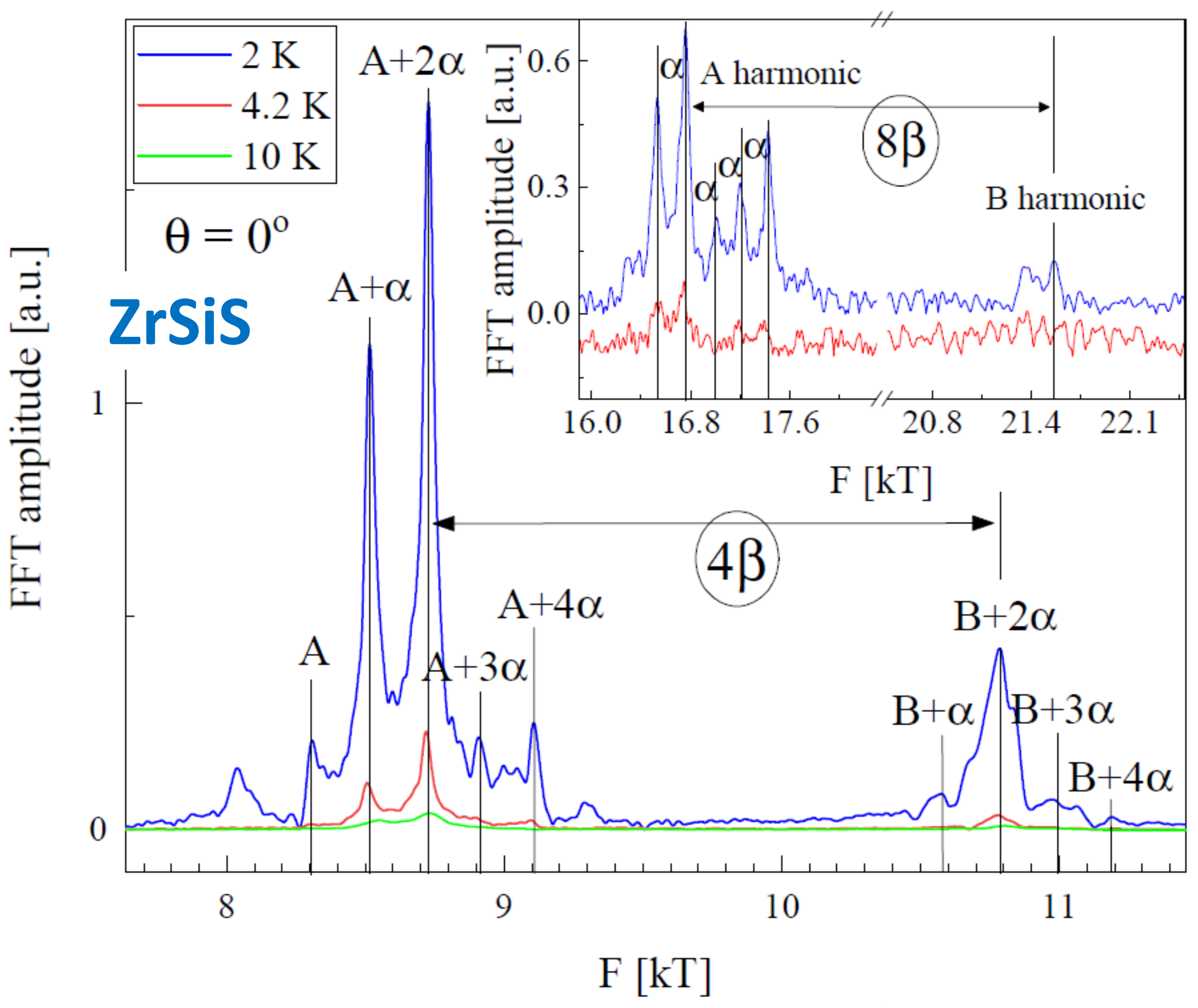
High frequency contribution above ~13 T, strongly dependent on the direction of $\vec{B}$.

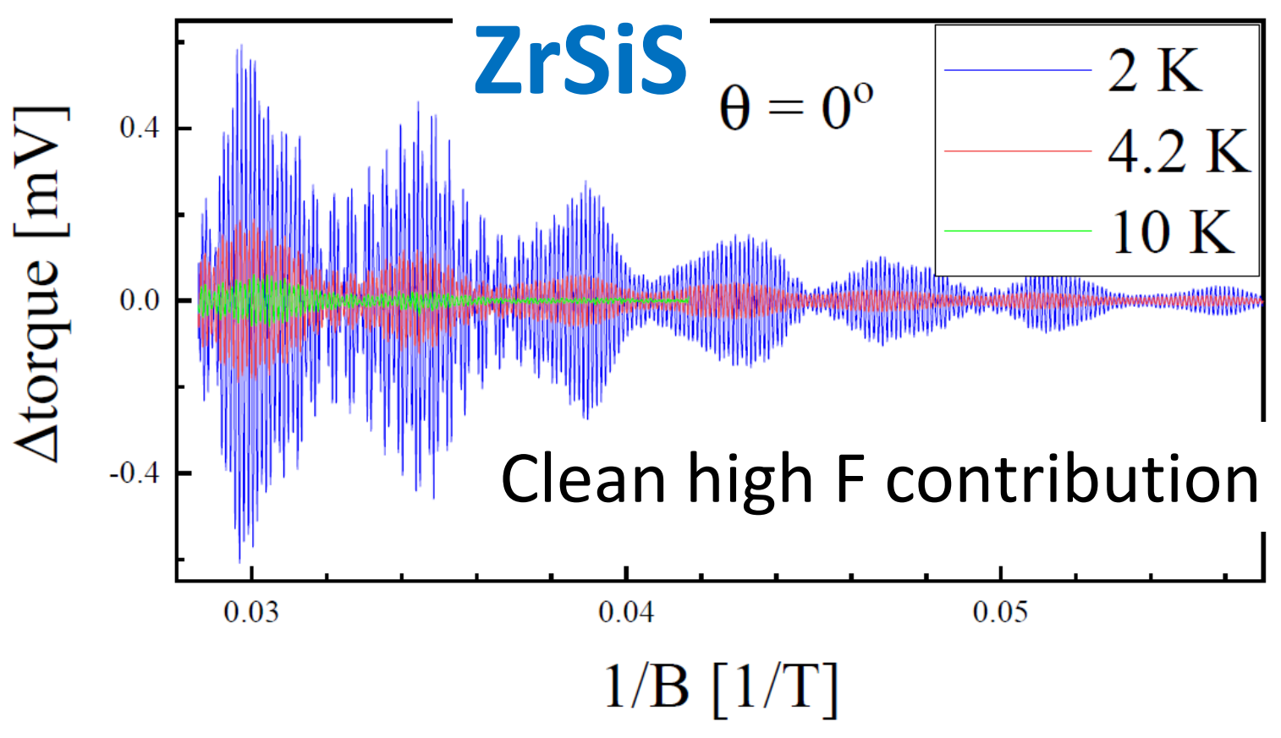
FFT of torque signal (for $\theta = 0^{\circ}$) vs $1/B$ detects a few groups of frequencies: low frequencies up to 1000 T and 4 regions of high frequencies.

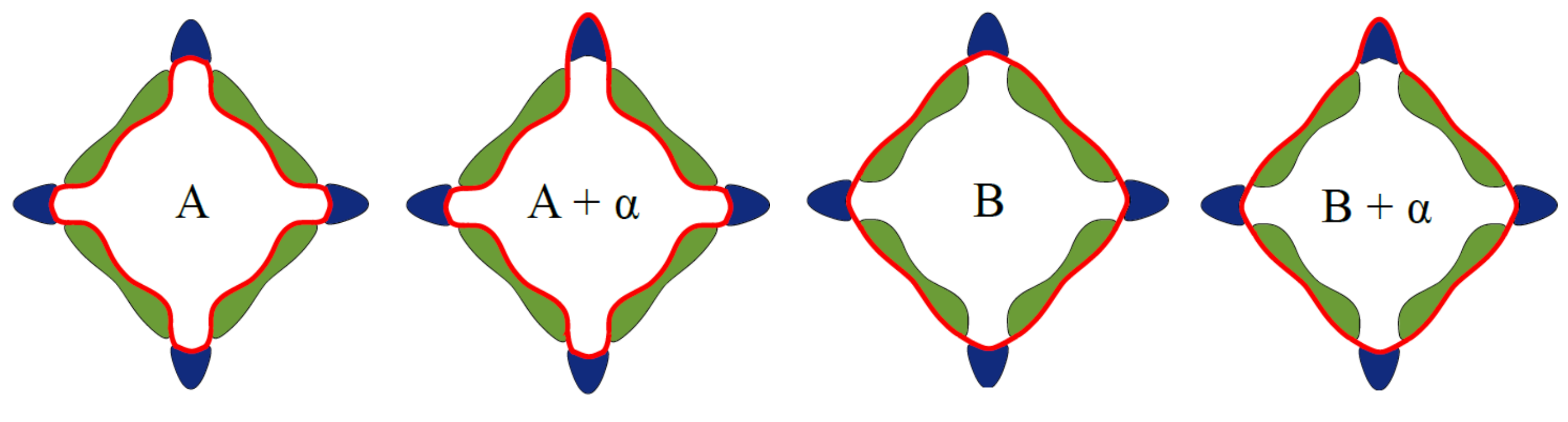


High frequencies

FFT of clean high F contribution







Appearance of high F can be explained by the effect of magnetic breakedown.

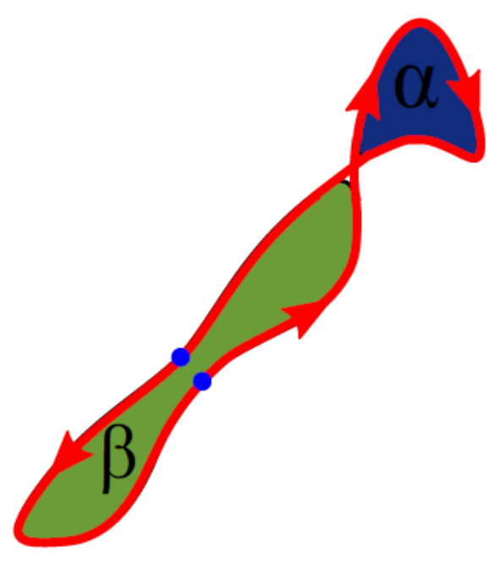
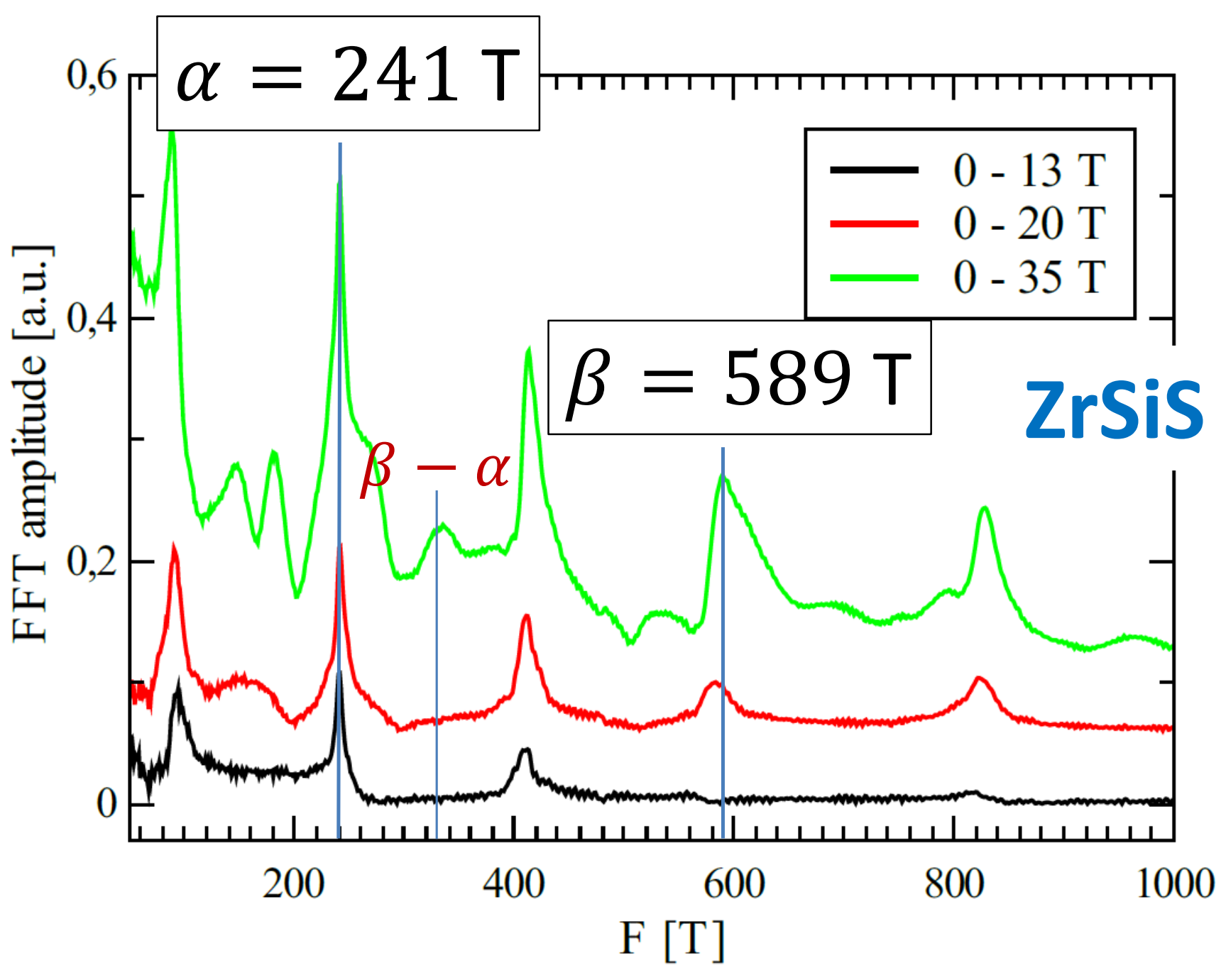
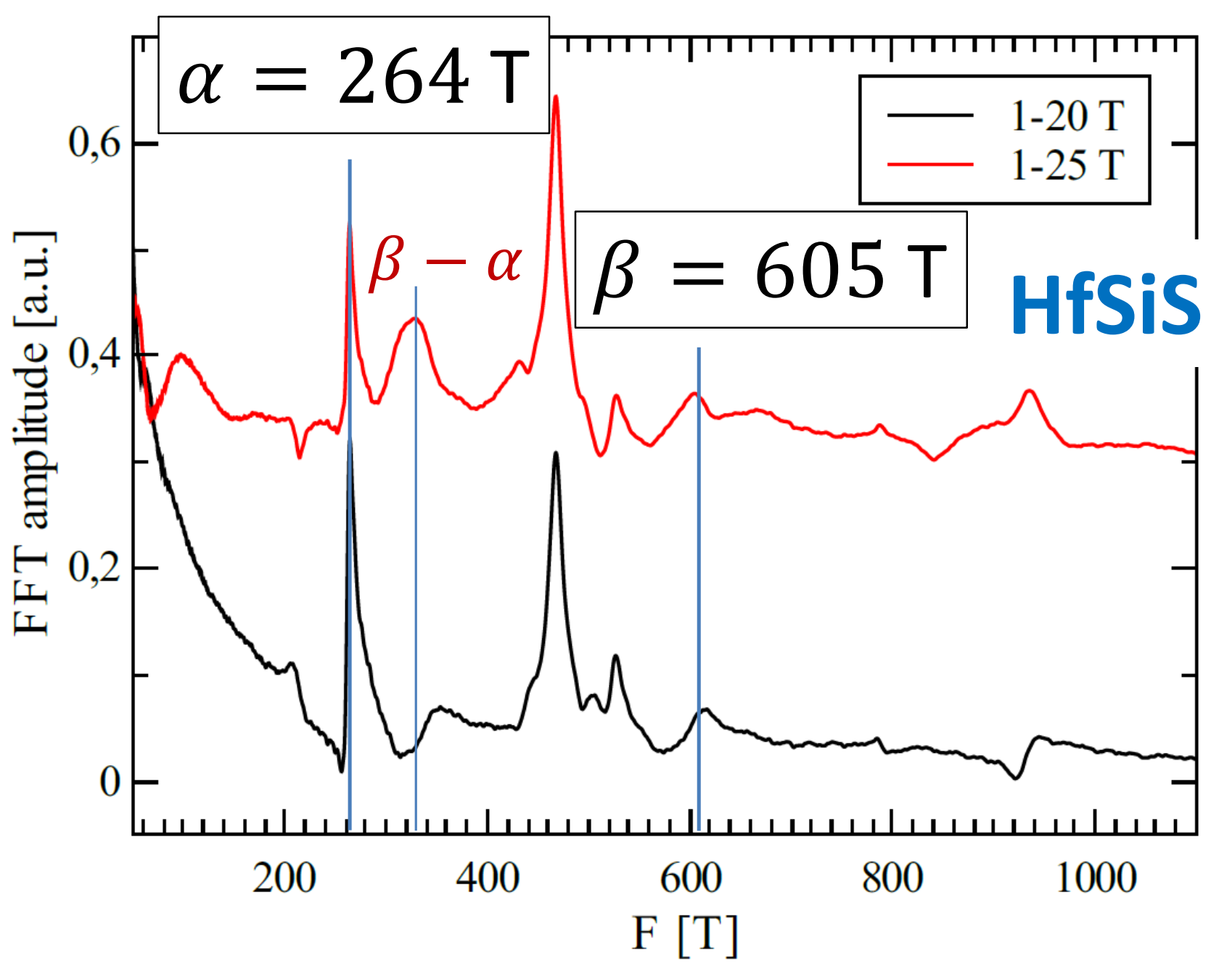


Figure of 8 electron orbit results in frequency $\beta - \alpha$.

Low frequencies





hrzz Croatian Science Foundation
PMF
Sveučilište u Zagrebu
HFML Science in High Magnetic Fields

Acknowledgments

This work has been fully supported by Croatian Science Foundation under the project IP-2018-01-8912.

Conclusion

- Magnetic torque was measured by cantilever method up to 35 T in single crystalline samples of NLS ZrSiS and HfSiS. Strong quantum oscillations where observed.
- FFT of quantum oscillations reveals two sets of frequencies: low frequencies (up to 1000 T) and high frequencies between 7-20 kT.
- High frequency contribution can be explained by the effect of magnetic breakdown whose appearence is highly dependent on the angle between field and crystal c-axis.
- High frequency FFT spectrum analysis confirms predicted α- and β-pockets in FS of WSiS (W = Zr, Hf) with corresponding frequencies.

References:

[1] Chen, C. *et al* (2017). Physical Review B. **95**, 125126
[2] Pezzini, S. *et al (2017). Unconventional mass enhancement around the Dirac nodal loop in ZrSiS.* nature physics **14**, 178–183
[3] Solyom, J. (2009). Fundamentals of the physics of solids (volume 2).
[4] M. R. van Delft *et al. Electron-Hole Tunneling Revealed by Quantum Oscillations in the Nodal-Line Semimetal HfSiS.* Phys. Rev. Lett. **121**, 256602