Nodal line semimetal ZrSiS – Quantum oscillations in magnetic torque

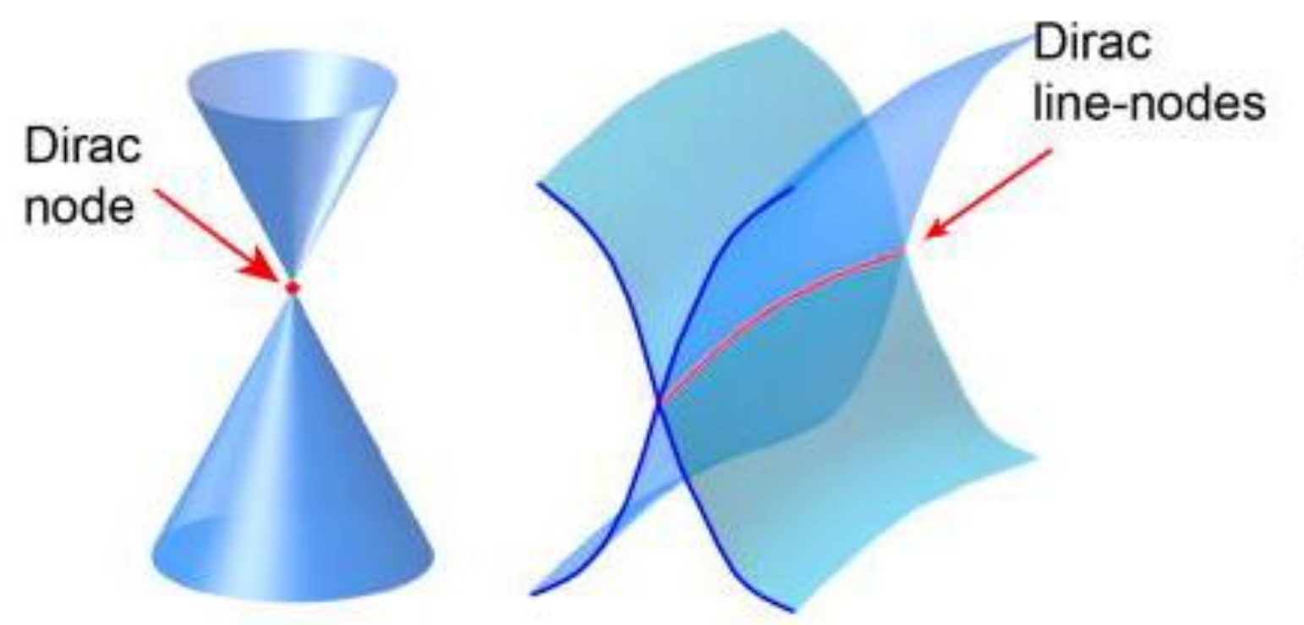
[1]F. Orbanić, [1]M. Novak, [1]B. Gudac [2]A. McCollam, [2]L. Tang, [1]I. Kokanović

E-mail: forbanic@phy.hr

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

ICPS 2018
34th INTERNATIONAL CONFERENCE ON THE PHYSICS OF SEMICONDUCTORS

Nodal line semimetal



Downloaded from [1]

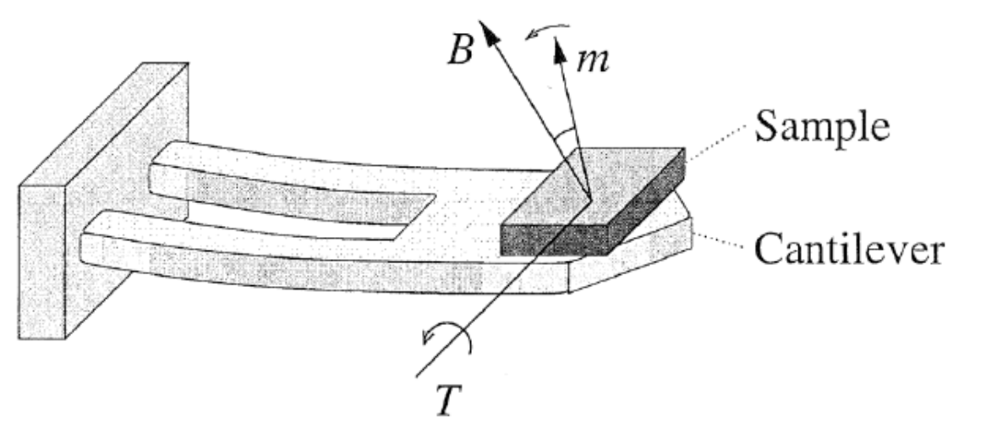
Dirac nodal fermions physics:

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

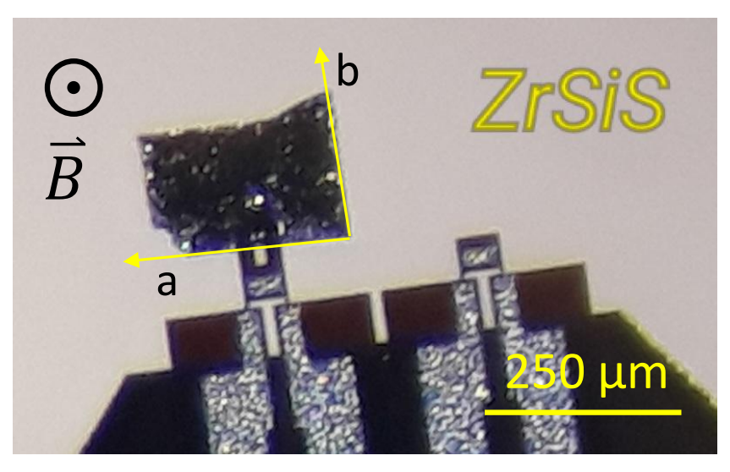
Symmetry protected band degeneracies which form lines.
Linear energy dispersion near these lines ⟶ Dirac line nodes.

Measurement technique

Piezoresistive cantilever method was used.



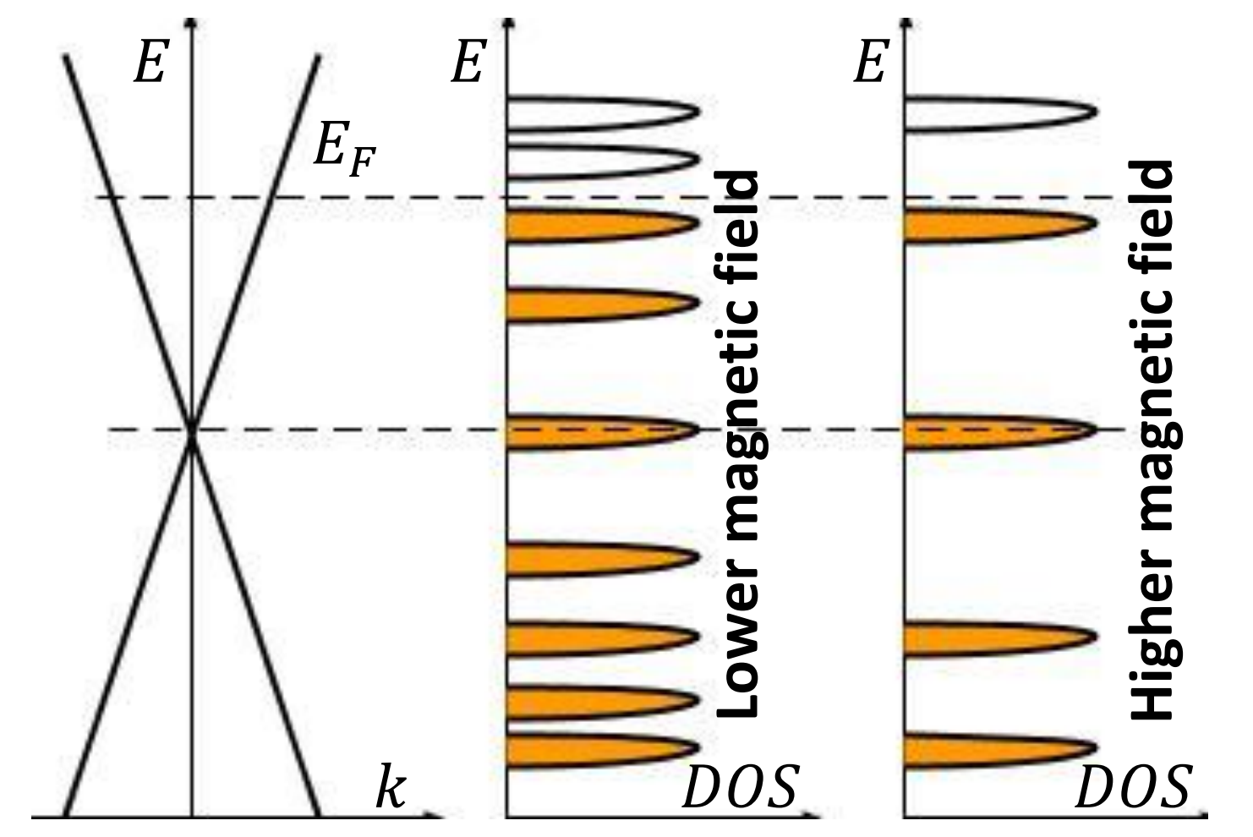
If material posses anisotropy, sample produces torque on lever, $T = \vec{M} \times \vec{B} \propto B^2$.



Sample glued on lever.

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

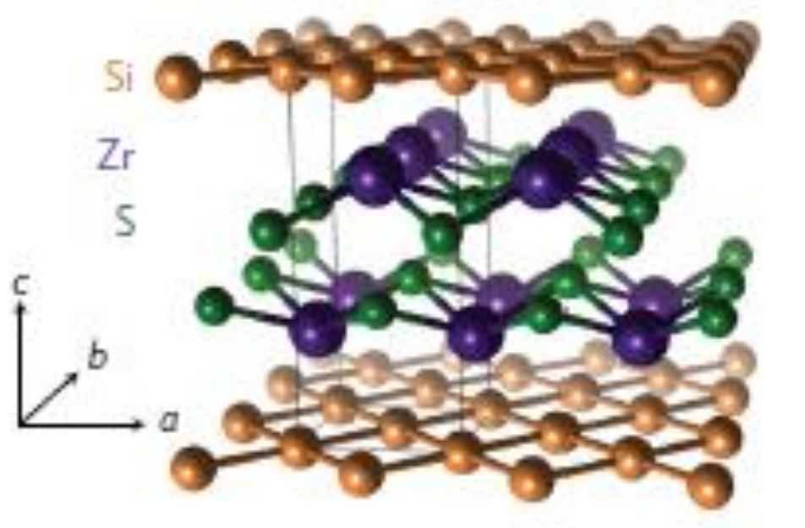


Electrons in a strong magnetic field ⟶ Landau levels. Increasing field leads to the periodicaly crossing of Landau levels and E_F ⟶ oscillation of physical quantities with 1/B, [3].

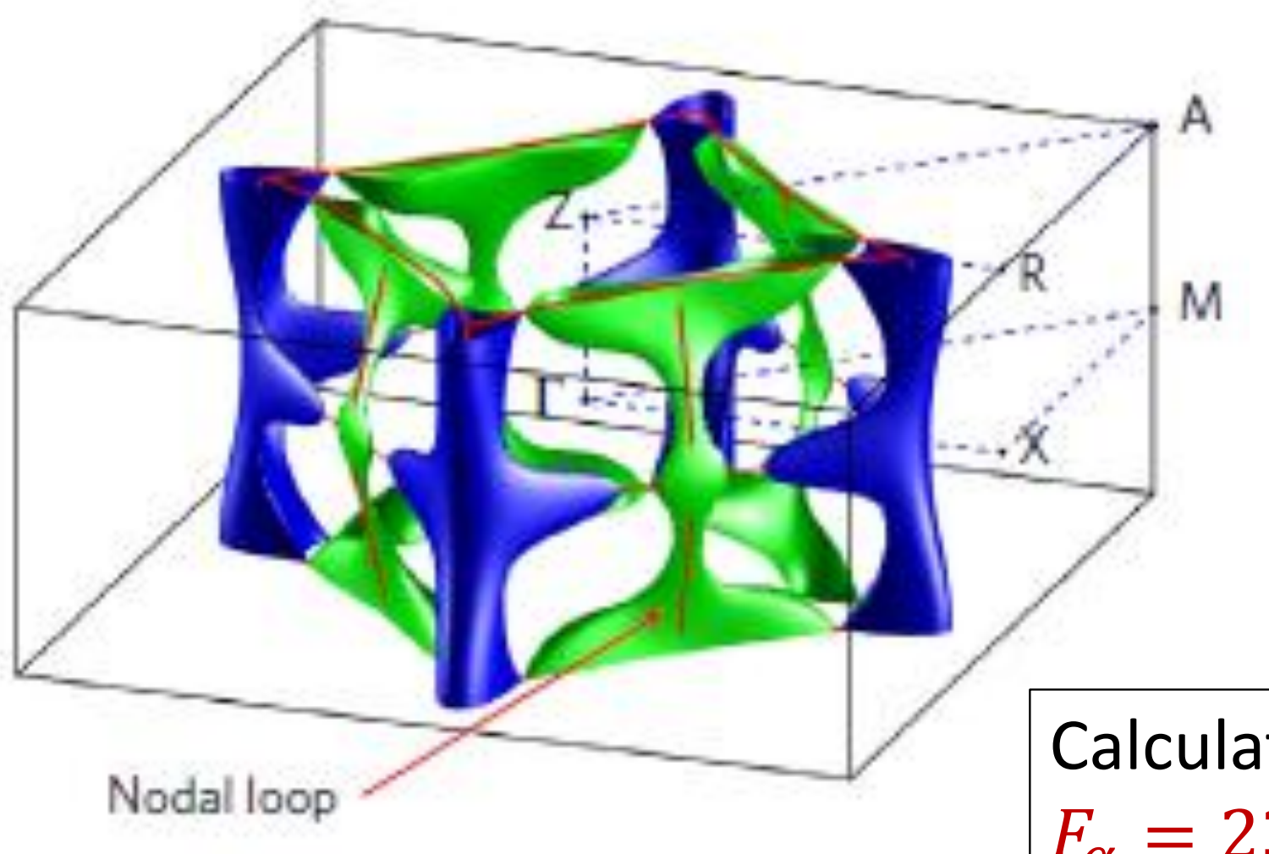
Frequency of oscillations is determined by the extremal cross sections of FS and plane normal to $\vec{B}$ $\longrightarrow$ $F = \frac{\hbar A}{2\pi e} = \frac{\hbar {k_F}^2}{2e}$

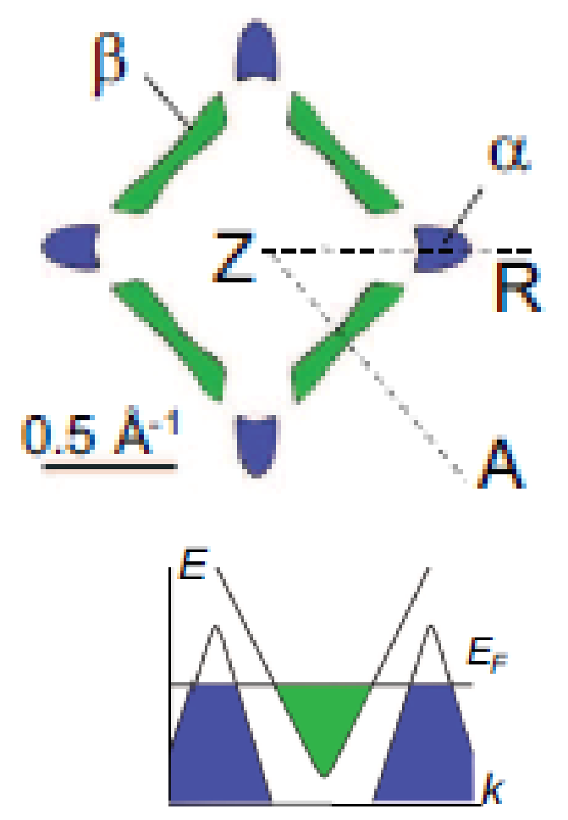
ZrSiS

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



Download from [2]

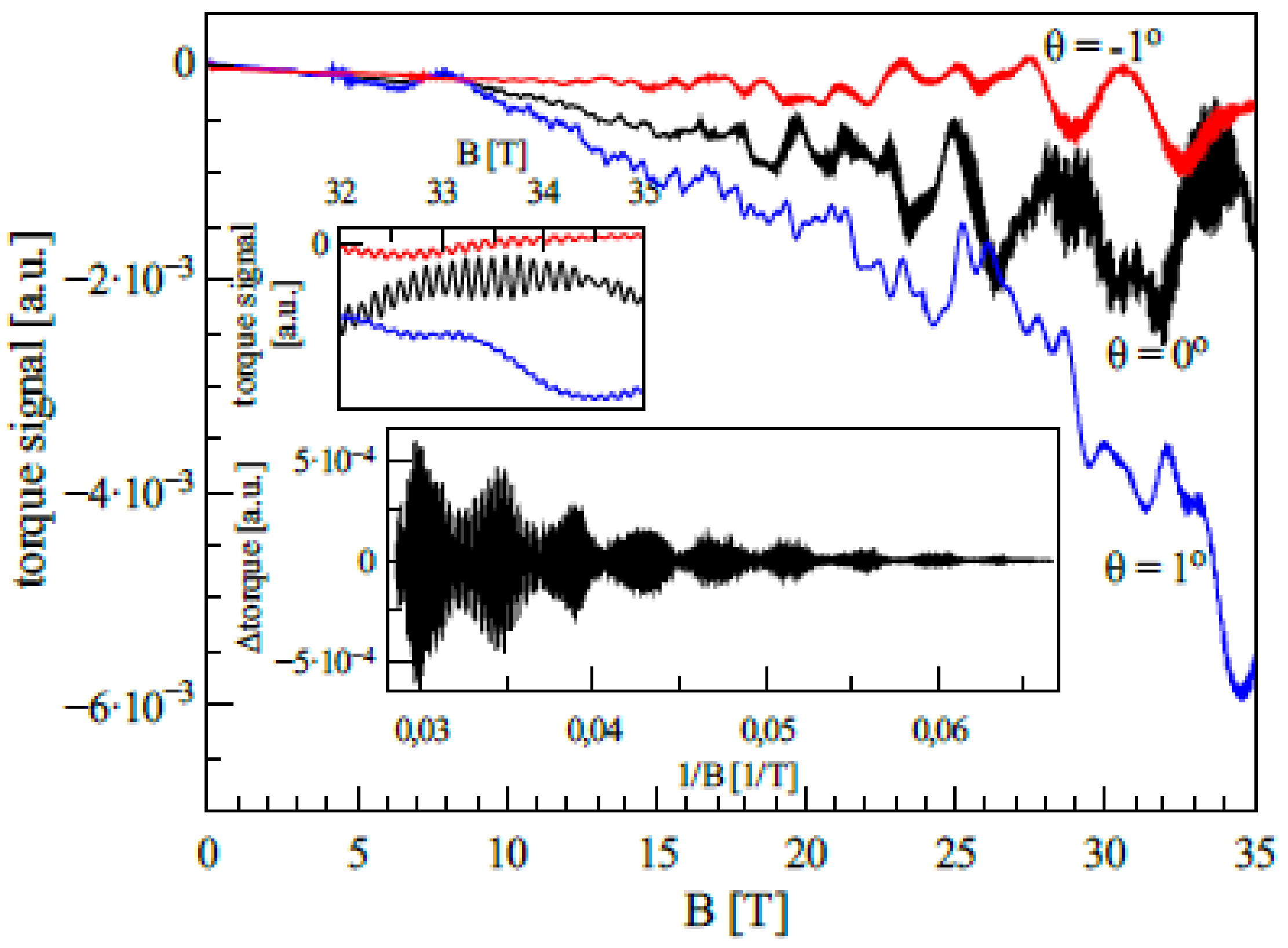




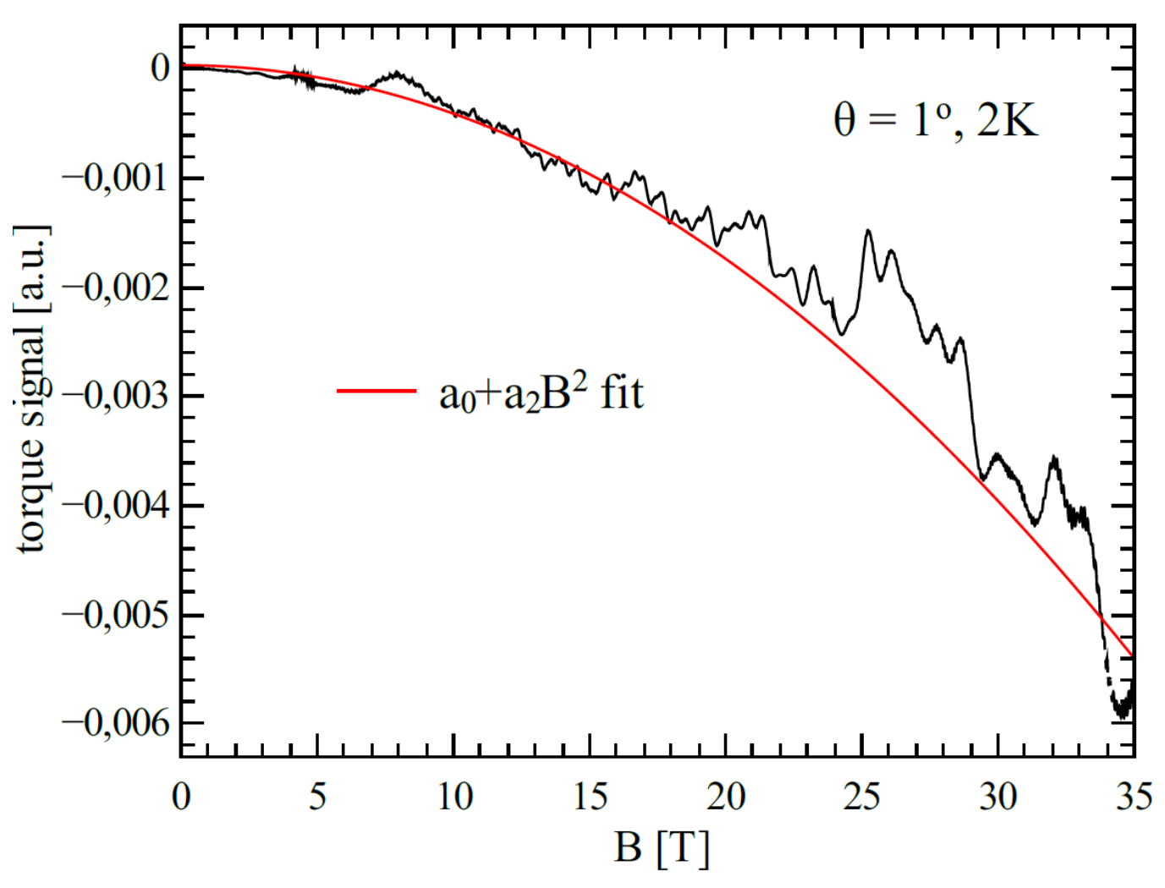
Calculated FS of ZrSiS consist of electron (β) and hole pockets (α). There is a small energy gap (10-20 meV) between pockets due to the spin orbit interaction.

Calculated frequency:
$F_\alpha = 235$ T,
$F_\beta = 596$ T.

Torque measurements

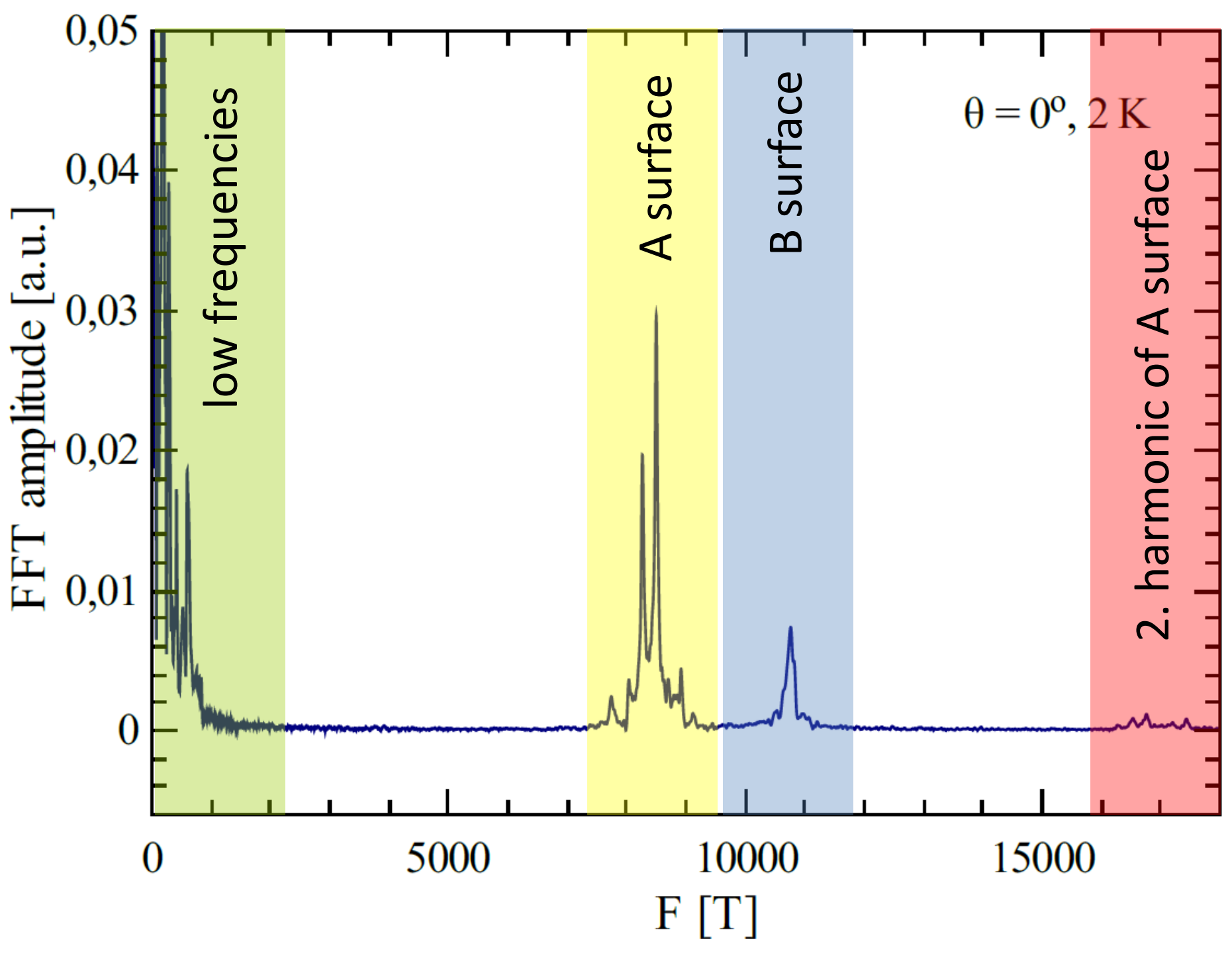


Torque signal consists of B^2 dependent background and quantum oscillation contributions superposed.

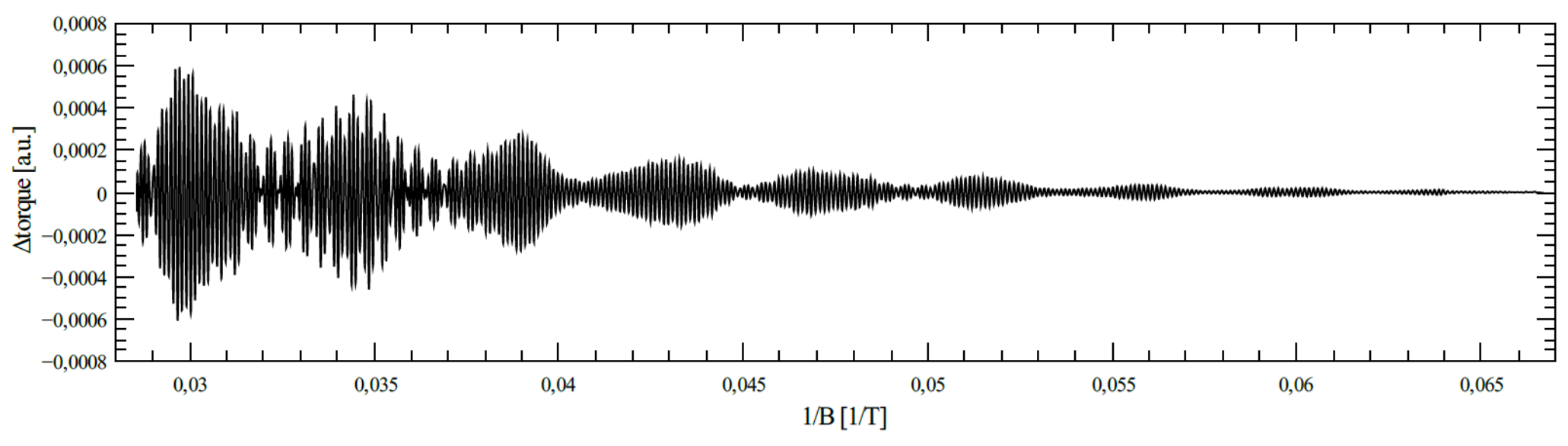


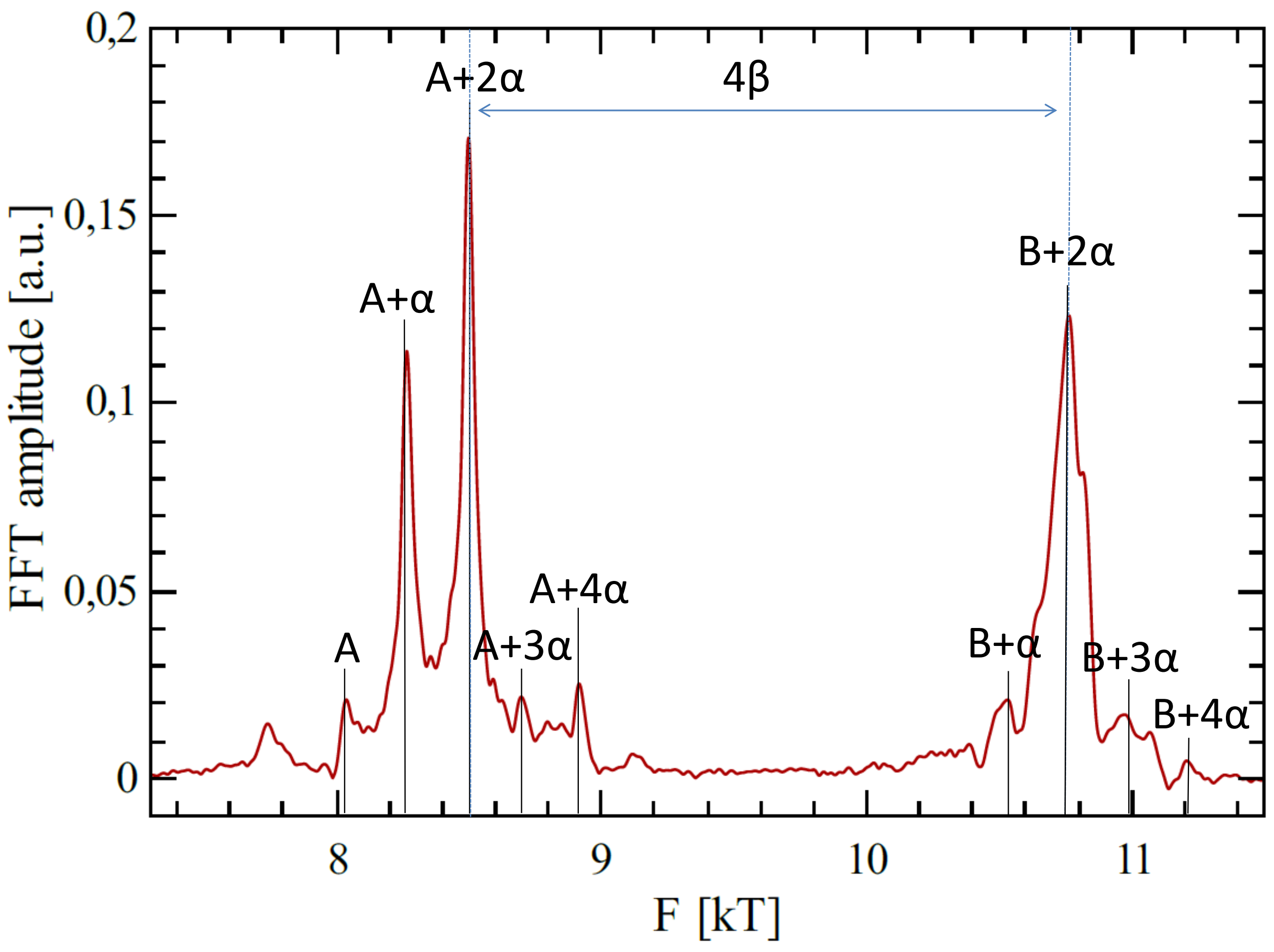
High frequency contribution above ~13 T, strongly dependent on the direction of $\vec{B}$.

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



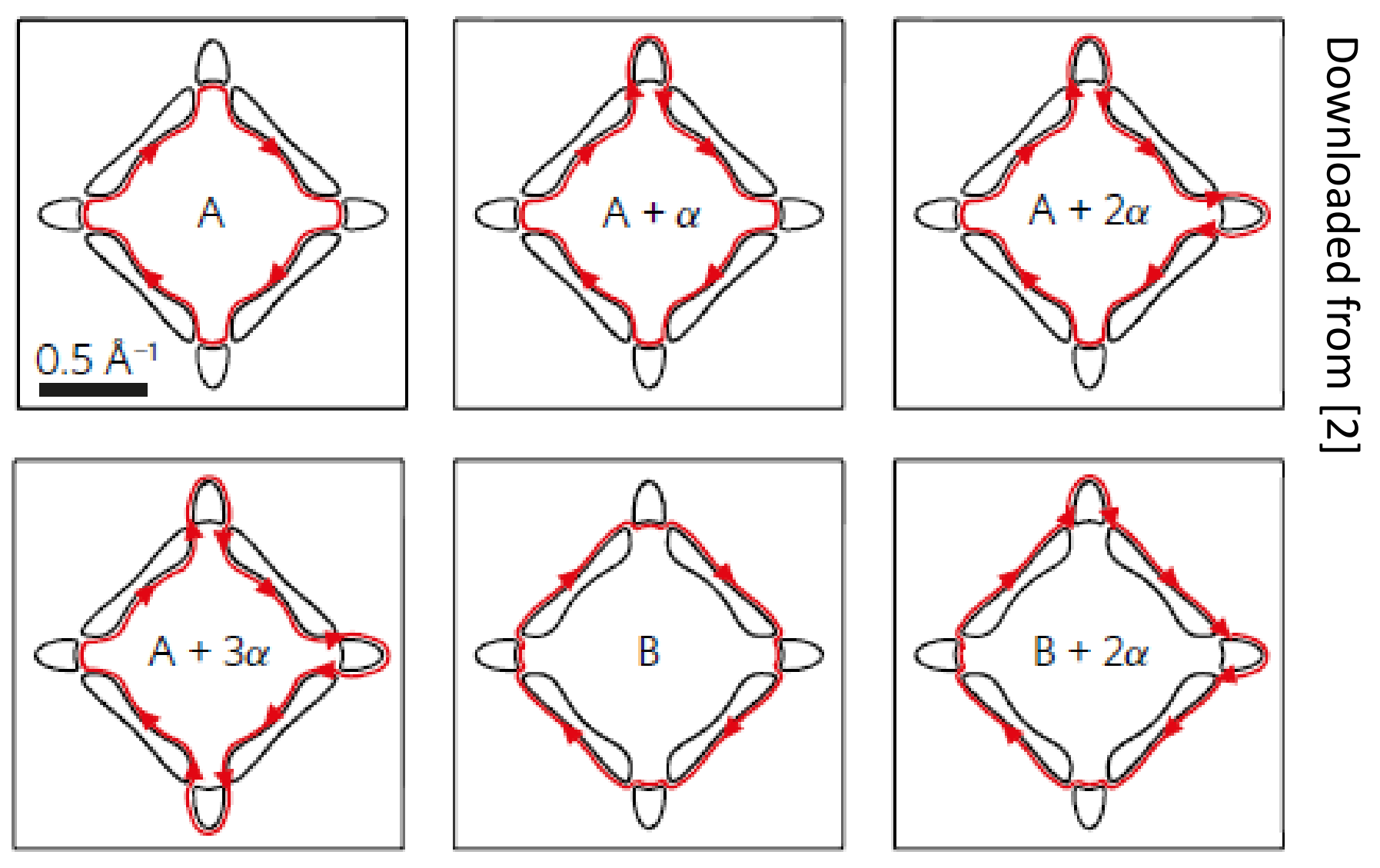
High frequencies





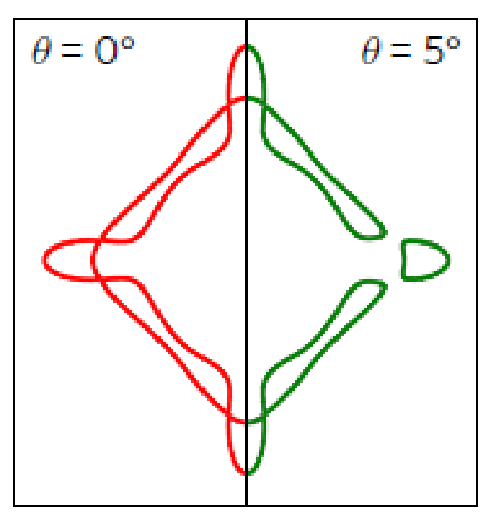
FFT of clean high frequency contributions.

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



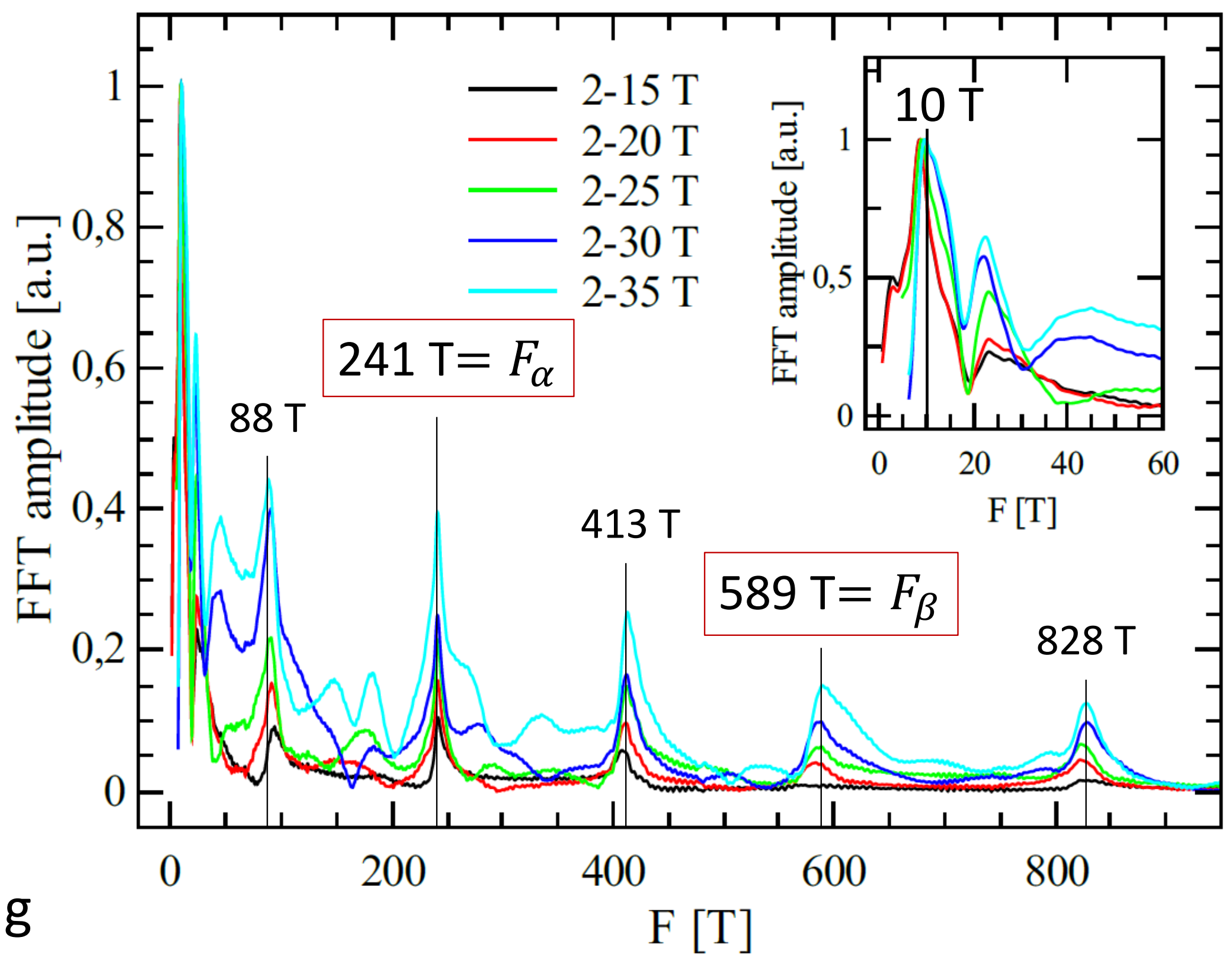
Downloaded from [2]

At sufficiently high magnetic field electrons can tunnel across the k-space gap which results in orbits of much bigger cross section (oscillation frequency).



k-space gaps in Z-R-A plane increase by tilting field from crystal c-axis. This explains a quick disappearing of high frequency contributions due small rotation of the field direction.

Low frequencies



Most of the low frequencies can be atributed to extremal cross sections of FS.

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

Acknowledgements
This work has been fully supported by Croatian Science Foundation under the project No. 6216.

Conclusion

- Magnetic torque in the single crystal ZrSiS was measured by cantilever method up to 35 T. 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.
- Most of the low frequencies can be atributed to extremal cross sections of FS (some of low frequencies are still unclarified).
- 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.

References:

[1] Chen, C. *et al* (2017). *Dirac line nodes and effect of spin-orbit coupling in the nonsymmorphic critical semimetals MSiS (M=Hf, Zr).* 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).