Magnetic torque anomaly in Dirac semimetal Cd_3As_2

[1]F. Orbanić, [1]M. Novak, [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 Niversity, Nijmegen, the Netherlands

E-mail: forbanic@phy.hr

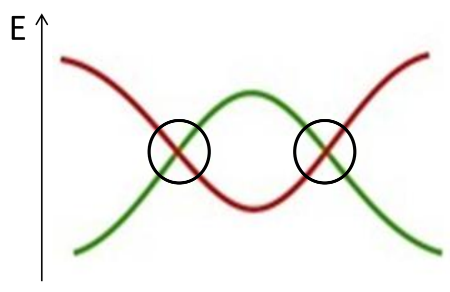
SOLID STATE SCIENCE & RESEARCH 2019

3D Dirac semimetal

Dirac dispersion in 3D (k-space) ⟶ 3D analogue of graphene.

Dirac fermion physics:

- High mobility and low effective mass.
- Large LMR.
- Interesting transport properties.
- Fundamental physics (Dirac/Weyl).

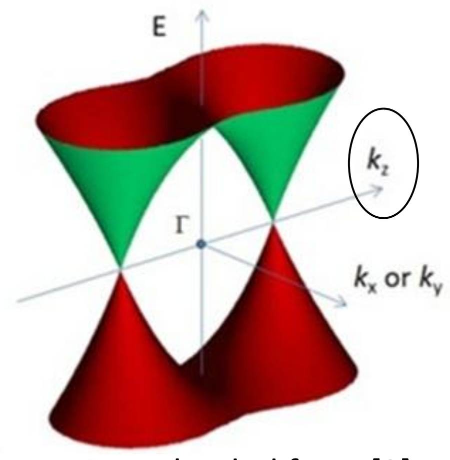


Cd_3As_2

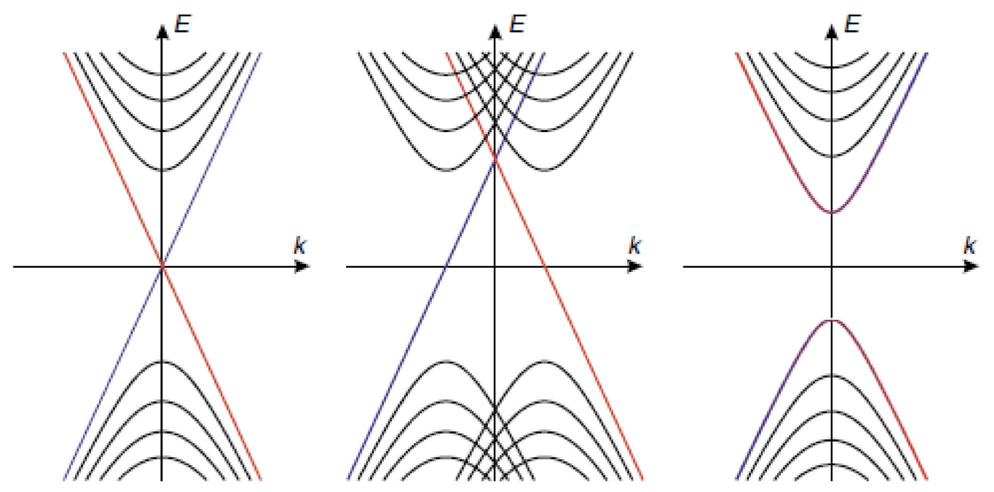
⟶ 3D Dirac semimetal with symmetry protected pair of Dirac points at Z-Γ-Z line.

Single crystals synthesized by modified CVD technique.

B-field along symmetry axis can splits Dirac point into two Weyl points.



Downloaded from [2]



Dirac | Field along symmetry axis Weyl | Field perp. to sxmmetry axis

Downloaded from [1]

Transport measurements

⟶ Magnetoresistance up to 16 T.

$m_c^* = 0.028 m_e$

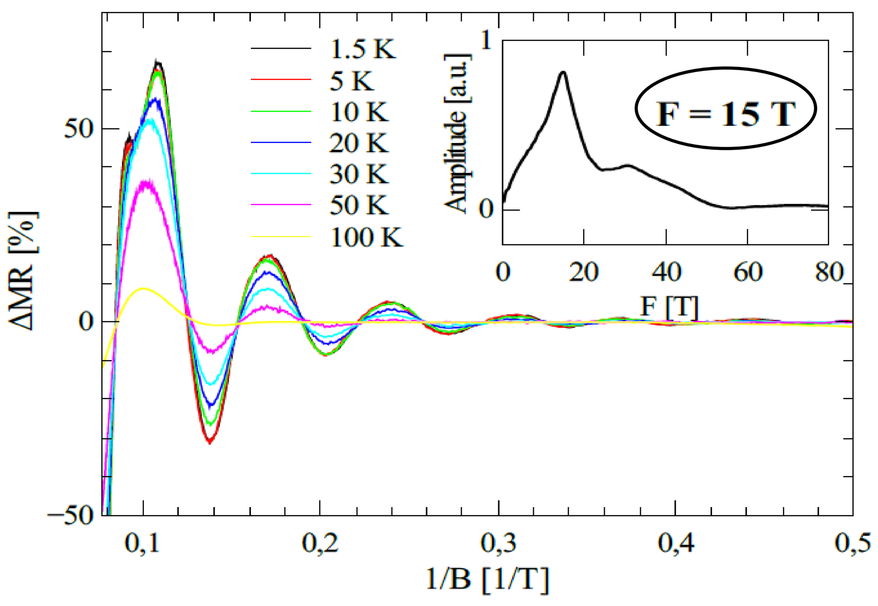
$T_D = 35.7$ K

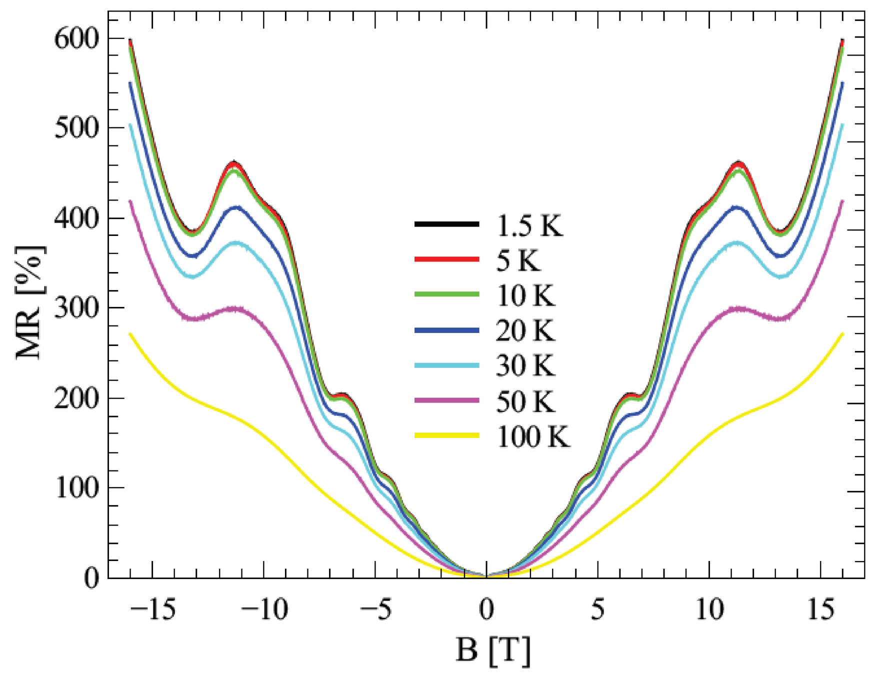
$\tau_Q = 2.14 \cdot 10^{-13}$ s

$\mu = 1.34 \cdot 10^4$ cm²/Vs

$n = 3.28 \cdot 10^{17}$ cm⁻³

$E_F = 124$ meV





Magnetization in the quantum limit

Energy levels in B-field for different types of electrons [1]:

$$\varepsilon_{n,k} = \begin{cases} \frac{\hbar e B}{m}(n+\gamma) + \frac{\hbar^2 {k_z}^2}{2m} & \text{Trivial } (\gamma = \frac{1}{2}) \\ \hbar v_F \sqrt{2B(n+\gamma) + {k_z}^2} & \text{Weyl } (\gamma = 0) \\ \hbar v_F \sqrt{2B(n+\gamma+C^2 \sin^2\theta) + {k_z}^2} & \text{Dirac } (\gamma = 0) \end{cases}$$

Magnetization in quantum limit

$M_{n=0} = -\frac{\partial \varepsilon_{0,k}}{\partial B}$

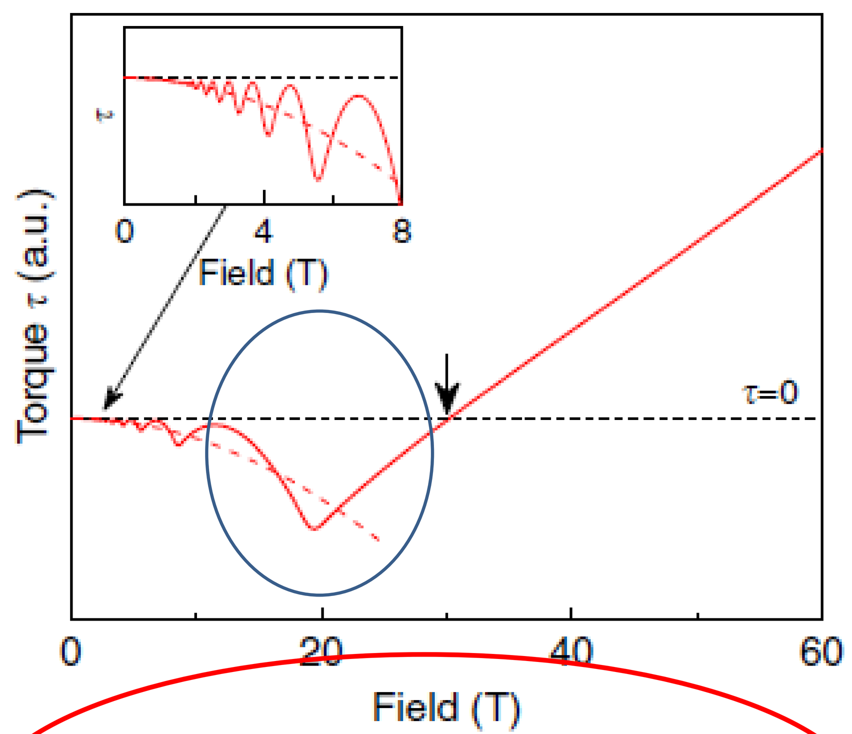
θ – angle between B and line connecting two Dirac points

C – material dependent parameter

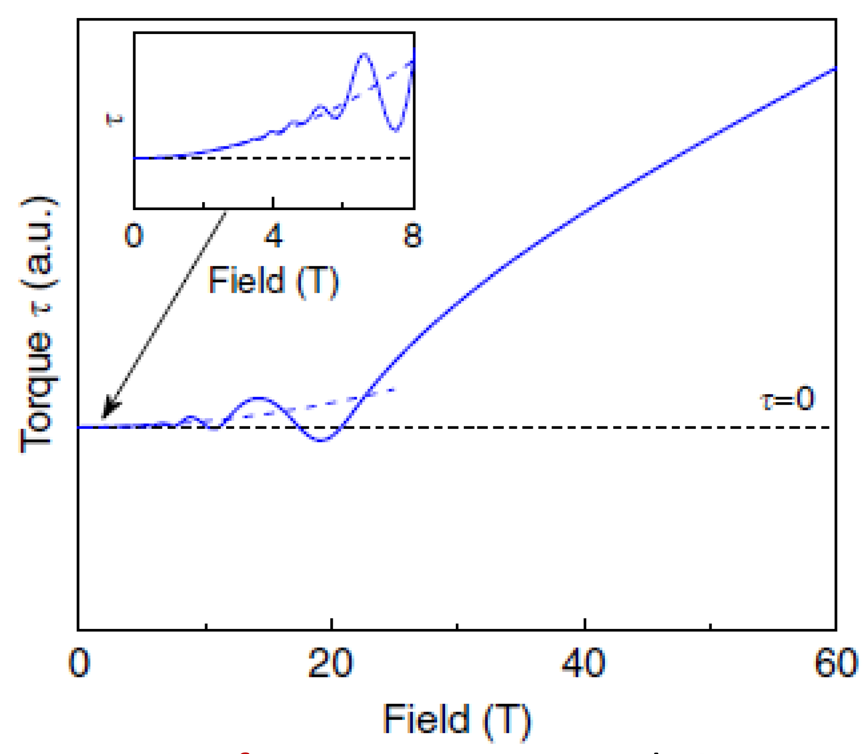
Dirac – B-field perpendicular to the symmetry axis ⟶ massive fermion
– B-field in the direction of the symmetry axis ⟶ weyl

Simulated behaviour of torque near the quantum limit [1]:

Downloaded from [1]



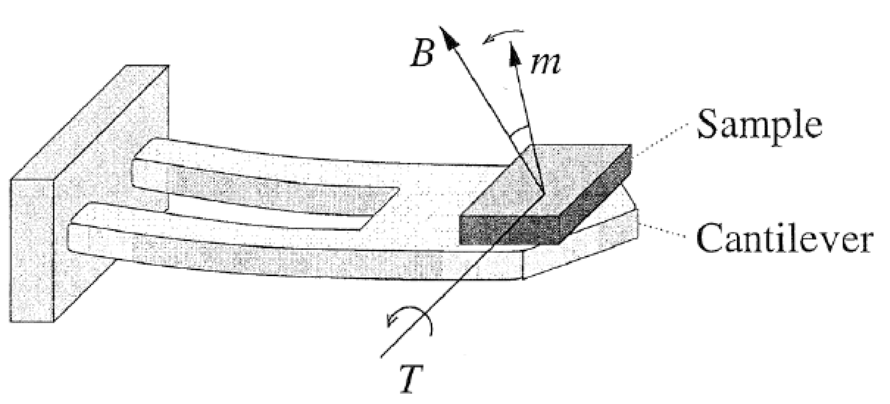
Weyl – change from diamagnetic to paramagnetic response leading to the torque reversal.



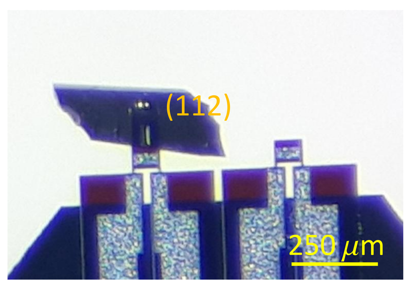
Massive fermion – no anomaly in magnetic response near quantum limit and no sign reversal in the torque.

Magnetic torque measurements

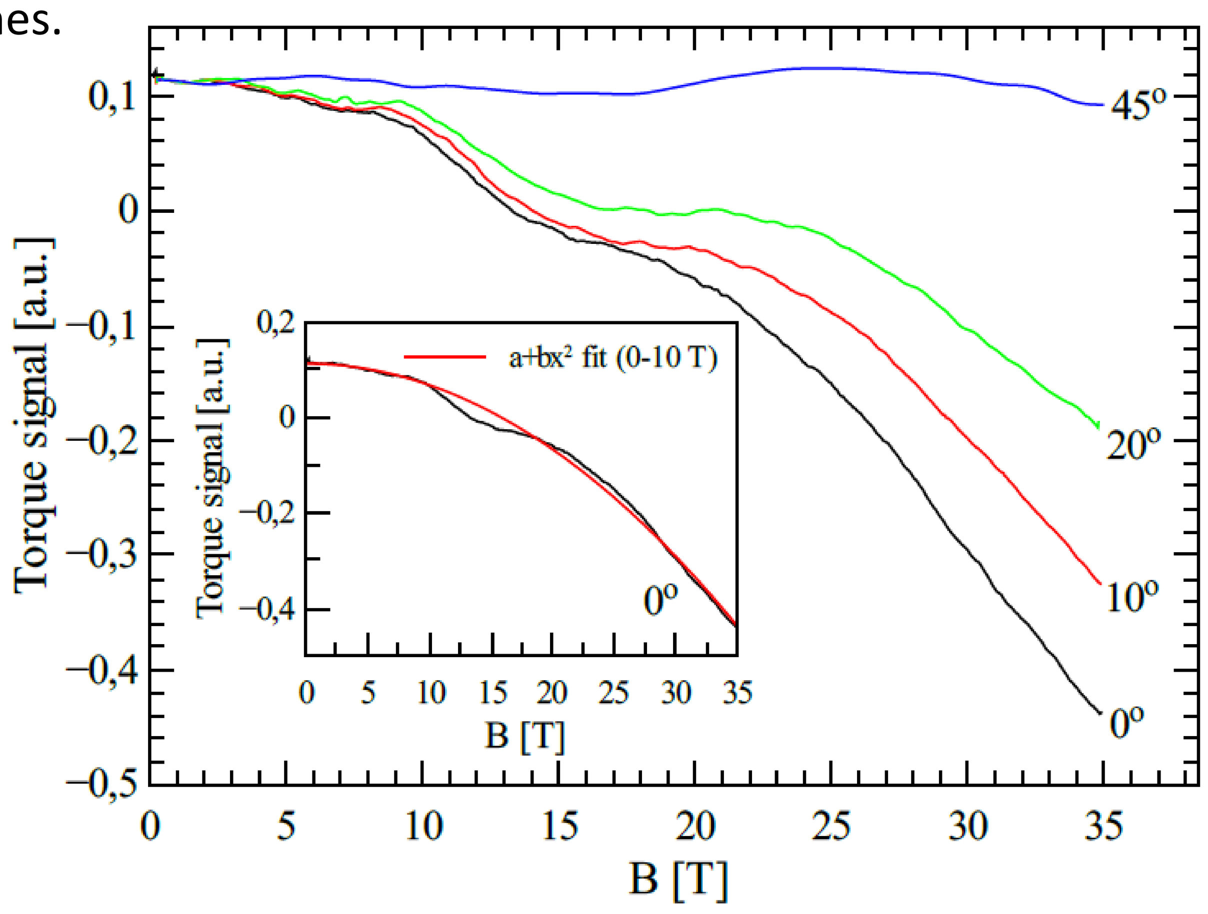
- By **piezoresistive cantilever technique**.
- Two different samples glued on different planes.
- At 4.2 K up to 35 T.

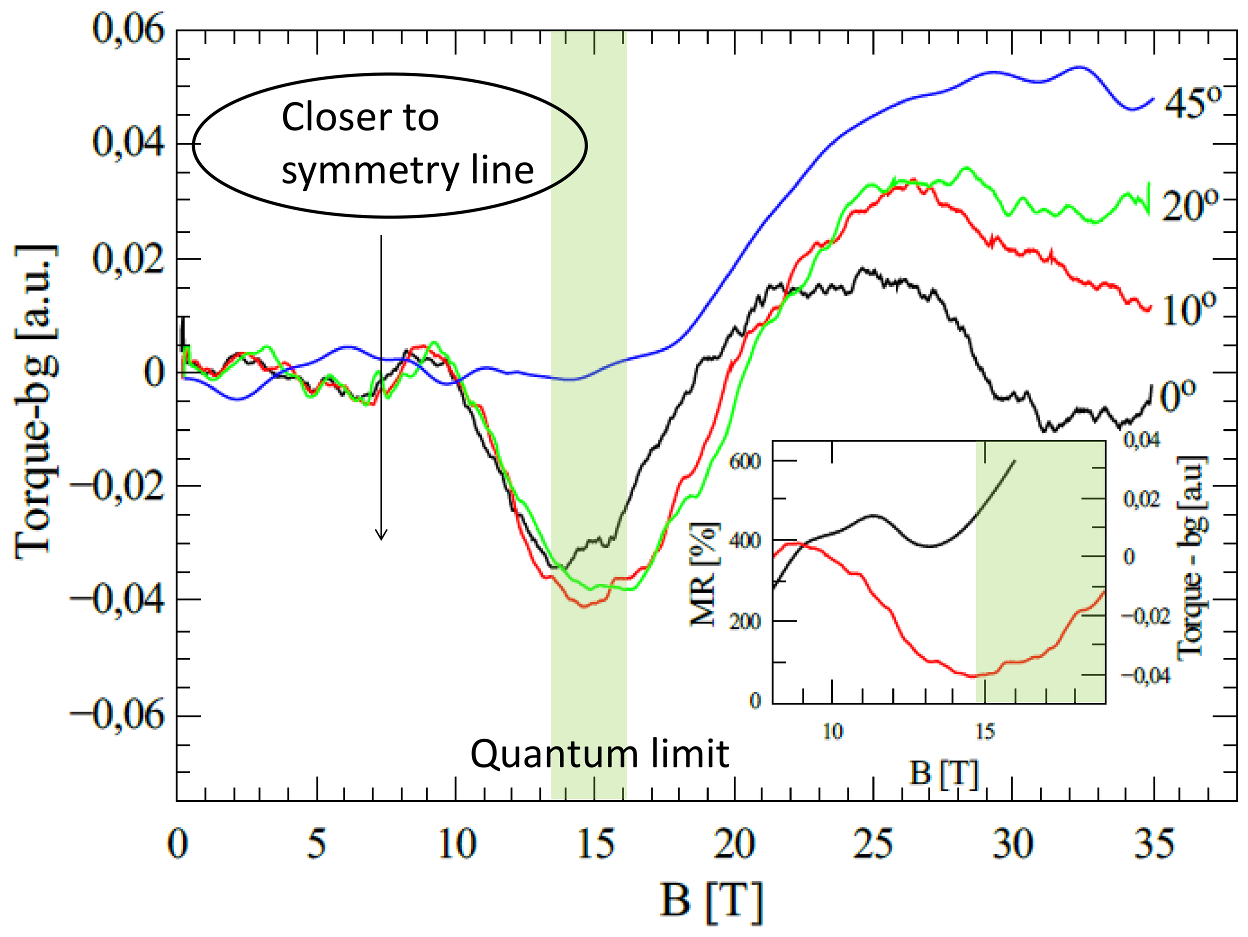


If material posses anisotropy, sample produces torque on lever, $T = \vec{M} \times \vec{B} \propto B^2$.



Angle is between field direction and normal to the sticking plane.





By entering the qunatum limit the torque anomaly appears. Anomaly and change in torque slope is highly suppressed at 45^o.

Quantum limit appears at the same field for different field directions indicating the sphericity of the Fermi surface (confirmed in SdH oscillations).

Conclusion

- Succsesfully synthesized low charge concetration Cd_3As_2 samples with lower quantum limit (Cd_3As_2 usually has F around 45-50 T).
- From SdH oscillations Fermi surface is found to be spherical leading to very small torque signal. In samples with higher charge concentration the Fermi surface is ellipsoidal [2].
- Anomalus and angle dependent behavior in the torque near the quantum limit has been found.

Acknowledgments

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

References:

[1] Moll, P. J. *et al.* (2016). Magnetic torque anomaly in the quantum limit of Weyl semimetals. *Nature Communications*, *7*.

[2] Borisenko, S. *et al.* (2014). Experimental realization of a three-dimensional dirac semimetal. *Physical Review Letters*, *113*(2).