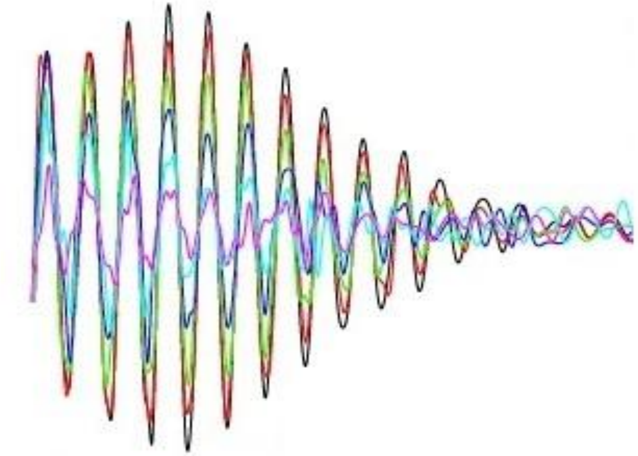

3D Dirac semimetals - Probing the Fermi surface with quantum oscillations

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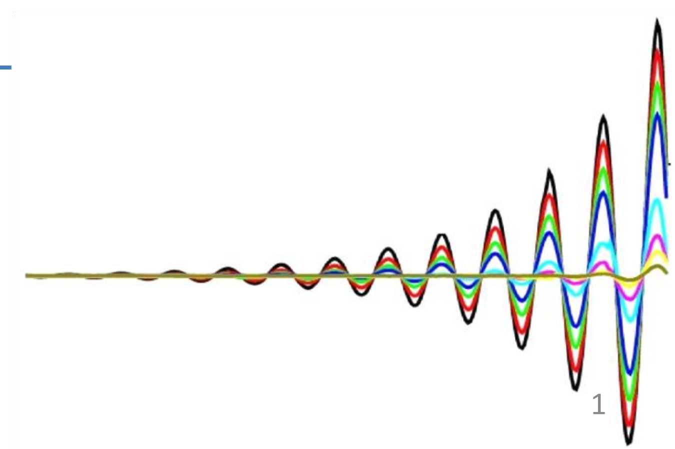
Laboratory for shynthesis and measurements of transport, magnetic and thermodynamic properties



3D Dirac semimetals

Dirac semimetal

- Linear dispersion near touching points.
- Band touching points.

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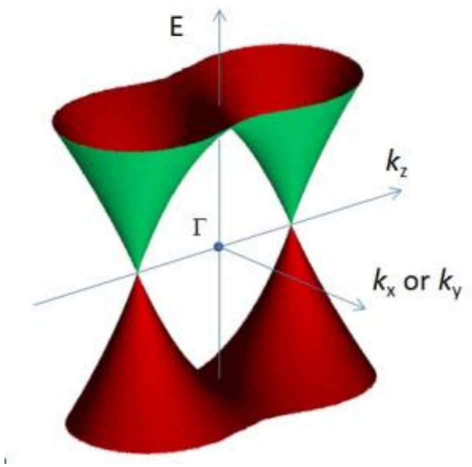
3D Dirac semimetal Cd_3As_2

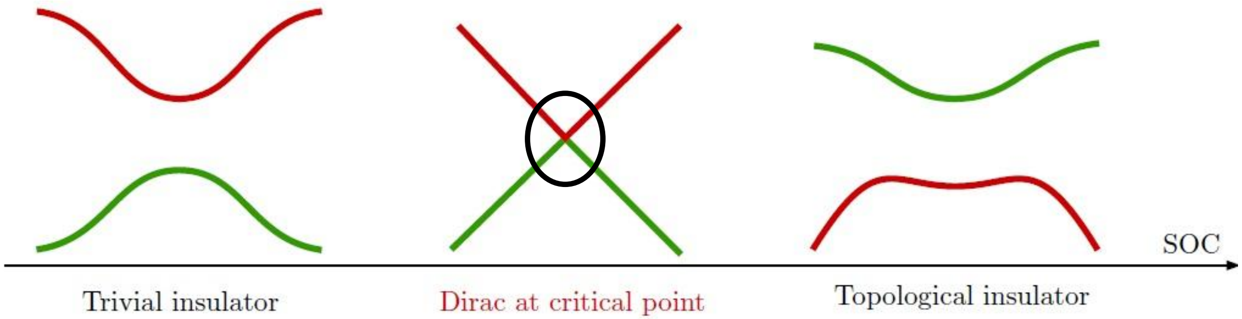


Dirac dispersion in 3D

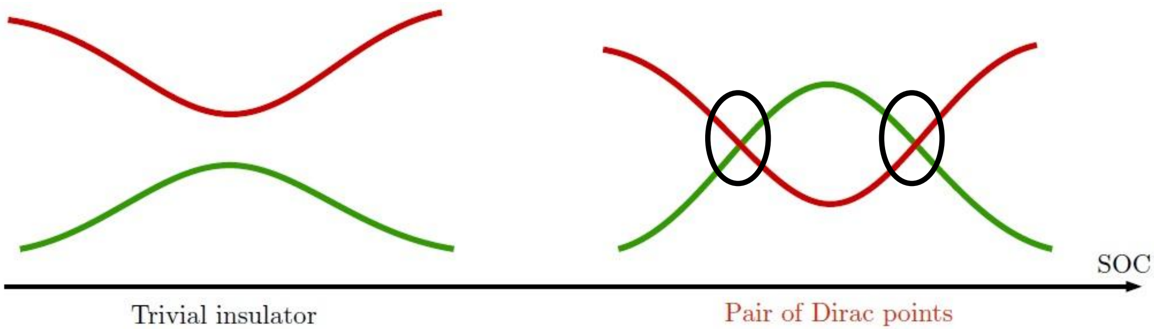
- 2D – graphene: $\hat{H}(\vec{k}) = v(k_x\sigma_x + k_y\sigma_y)$ ⟶ SOC $\sim\sigma_z$ opens a gap.
- 3D: $\hat{H}(\vec{k}) = v_{ij}k_i\sigma_j,\ \ j = x, y, z$ ⟶ Robust against perturbations!
- Interesting properties: fundamental physics, large LMR, high mobility, transport...

3D Dirac semimetals

- Two classes of 3D Dirac semimetals:



Dirac semimetal at NI-TI transition. ($Pb_{1-x}Sn_xSe$)

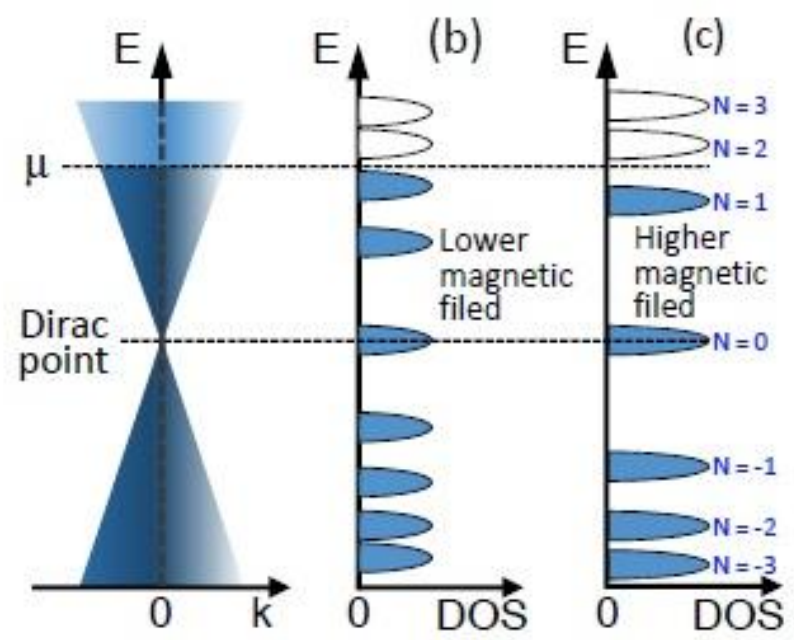


Intrinsic Dirac semimetal with a pair of symmetry protected Dirac points. (Cd_3As_2, $NaBi_3$)

SOC – spin orbit coupling

Quantum oscillations

- Electrons in strong B-field ⟶ Landau levels



Downloaded from J. Phy. Soc. Jap. **82**, 102001 (2013).

$$E_{\pm}(N) = \pm\sqrt{(2e\hbar v_f^2 B / c)N}$$

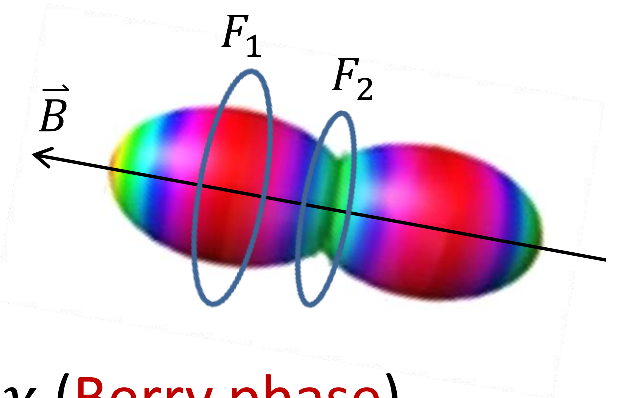
Periodic behaviour of DOS.

⇓

Oscillations of physical quantities with 1/B!

Magnetization → dHvA
Conductivity (resistivity) → SdH
Seebeck coefficient
Heat capacity

Quantum oscillations



- Lifshitz-Kosevich theory (3D):

$$\Delta M = AR_T R_D R_s \sin\left[2\pi\left(\frac{F}{B}-\frac{1}{2}-\frac{1}{8}+\beta\right)\right]$$

$$\Delta\sigma_{xx} = AR_T R_D R_s \cos\left[2\pi\left(\frac{F}{B}-\frac{1}{2}-\frac{1}{8}+\beta\right)\right]$$

$2\pi\beta = \gamma$ (Berry phase)

For Dirac fermions $\gamma = \pi$.

$$R_T = \frac{\frac{\alpha T}{B}}{\sinh\left(\frac{\alpha T}{B}\right)}$$

$$R_D = e^{-\frac{\alpha T_D}{B}}$$

$$R_S = \cos\left(\frac{\pi}{2} g \frac{m}{m_0}\right)$$

$$\alpha = 14.69\frac{m}{m_0} TK^{-1}$$

effective cyclotron mass

$$F = \frac{\hbar}{2e} k_F^2$$

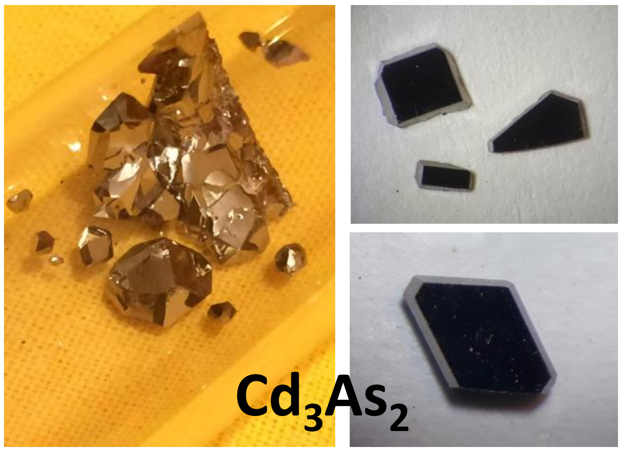
carrier density and Fermi surface shape (extremal cross sections of FS)

$$T_D = \frac{\hbar}{2\pi k_B \tau}$$

quantum scattering time

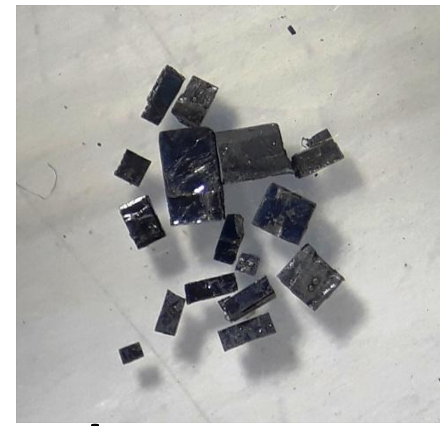
Materials

- Some of succsessfuly synthesized materials in our group:

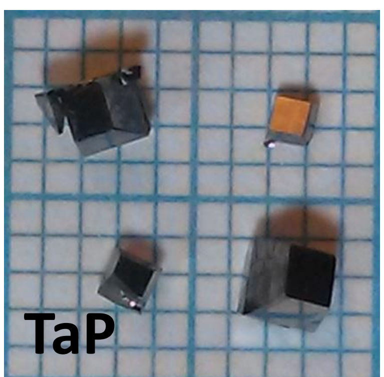


Cd_3As_2

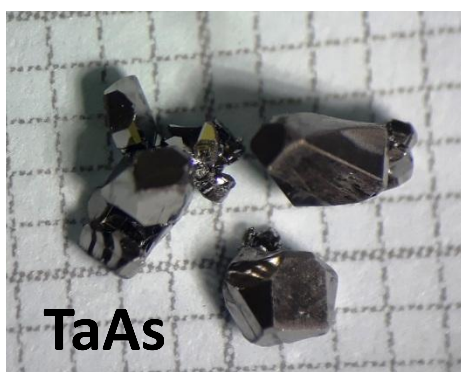
$BiSbTeSe_2$



$Pb_{0.83}Sn_{0.17}Se$



TaP

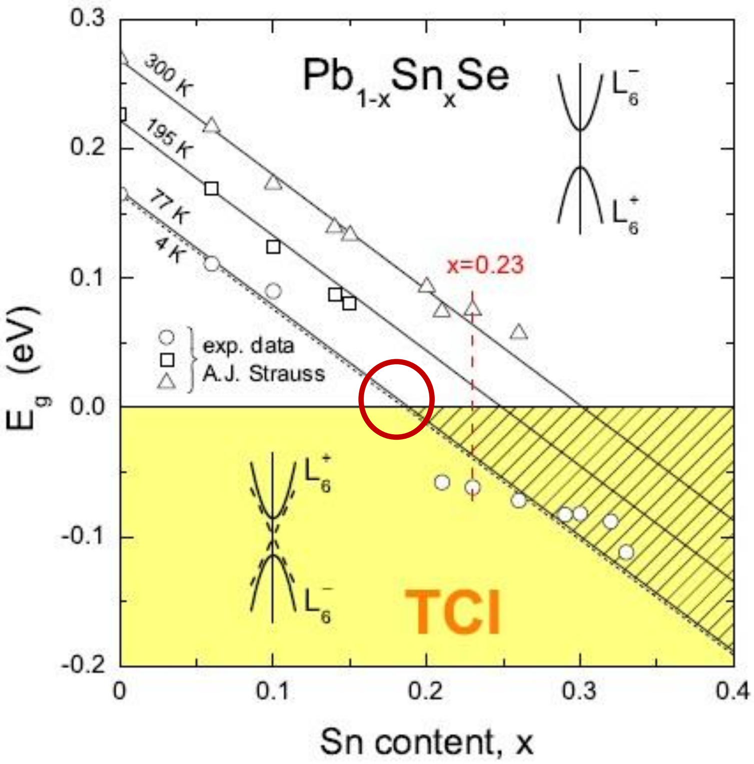


TaAs

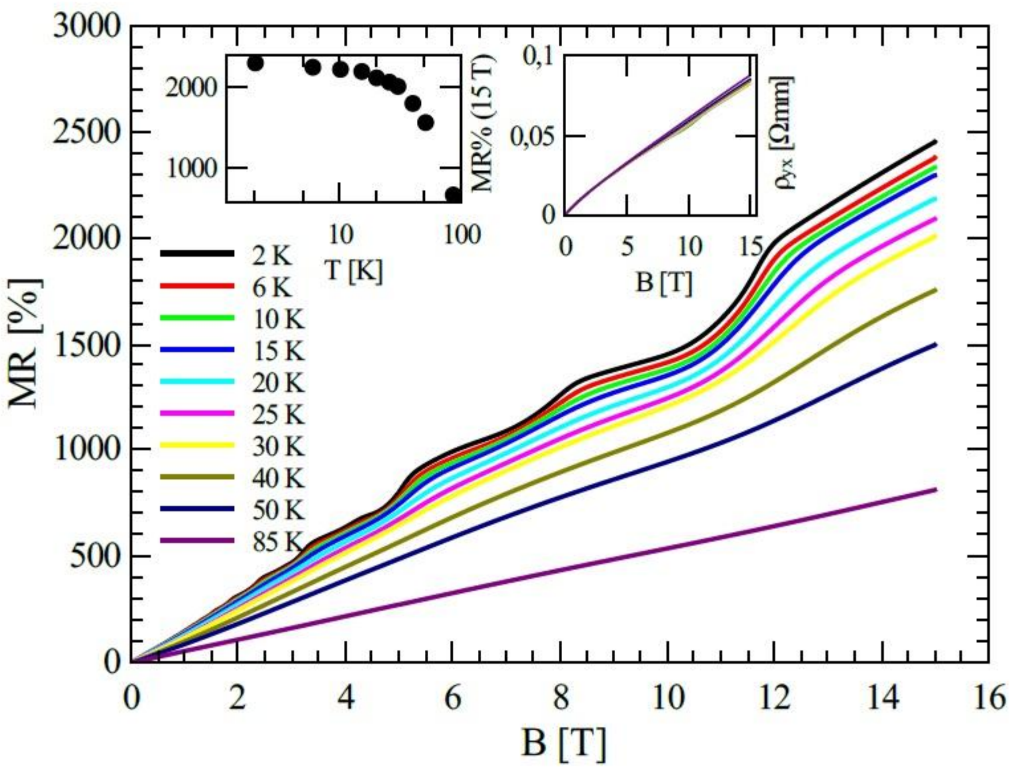
ZrSiS

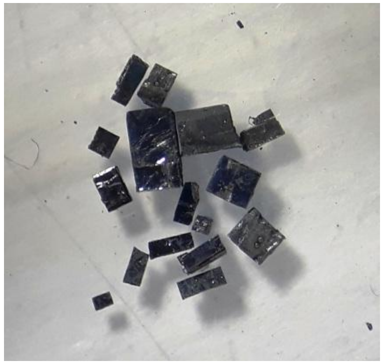
$Pb_{0.83}Sn_{0.17}Se$

- In $Pb_{1-x}Sn_xSe$ increasing x leads to NI-TCI transition. In $Pb_{0.83}Sn_{0.17}Se$ band gap closes → Dirac point.



Phys. Rev. 157, 608-611 (1967)

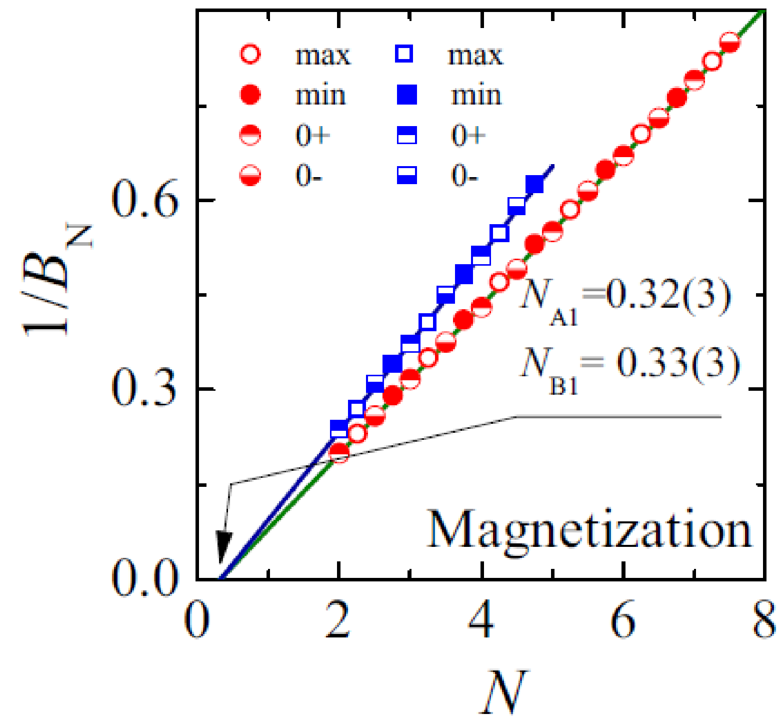


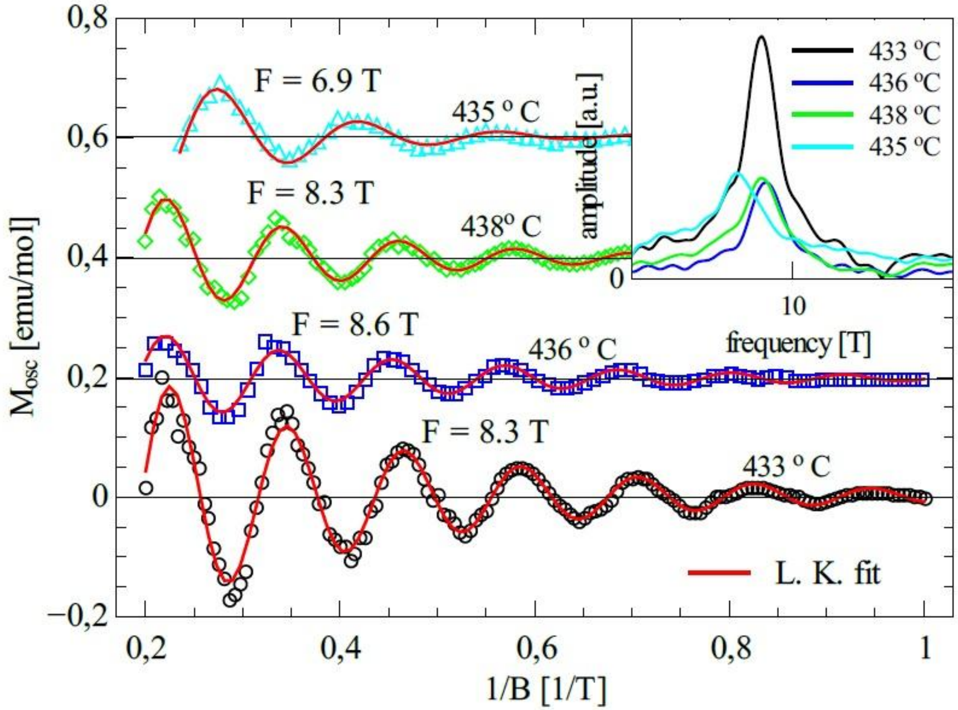


Magnetoresistance

$Pb_{0.83}Sn_{0.17}Se$

Landau level diagram



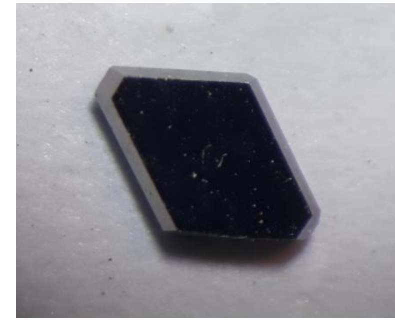


dHvA oscillations

$\gamma \approx \pi$
Dirac fermions

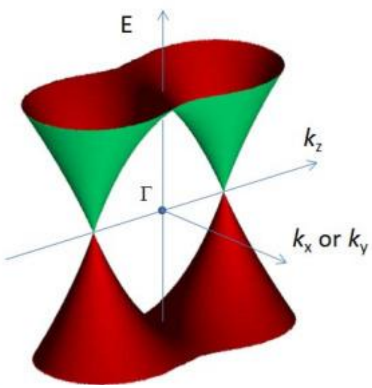
Orbanić et al, PRB, (2017)

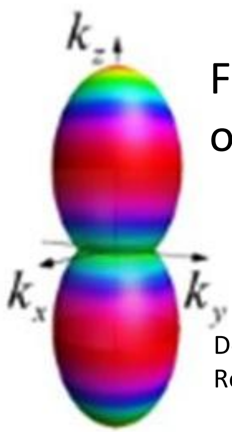
Cd_3As_2



- Intrinsic Dirac semimetal
- A pair of Dirac points in direction of rotational symmetry axis.

3D Dirac semimetal Cd_3As_2





Fermi surface of Cd_3As_2

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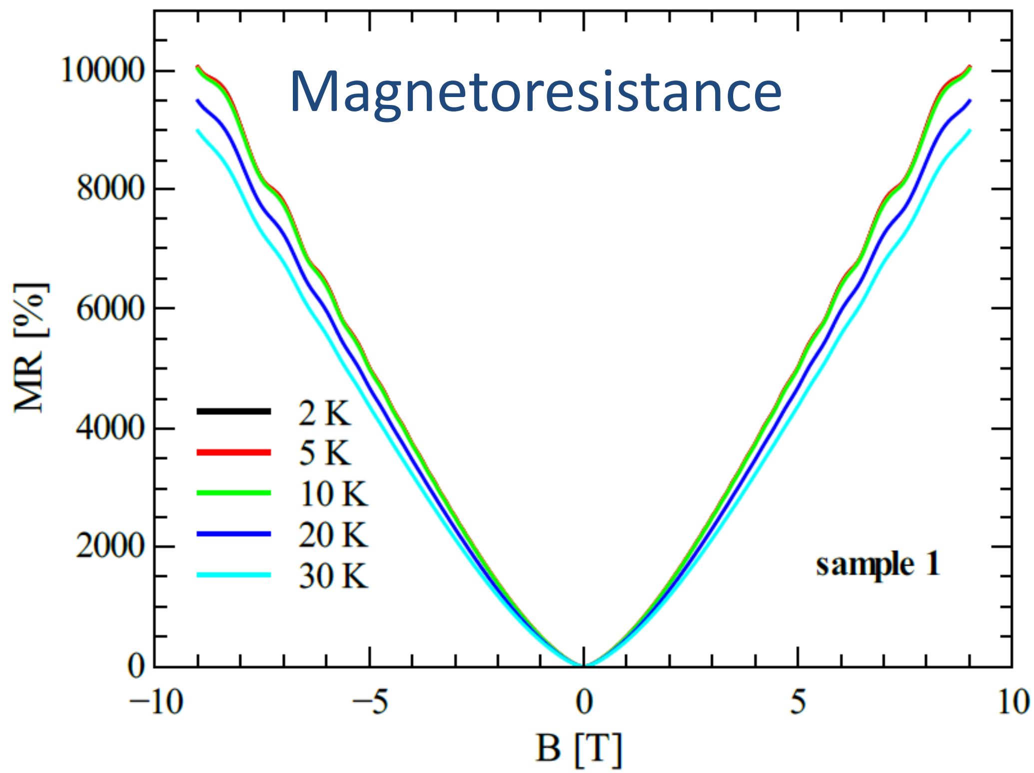
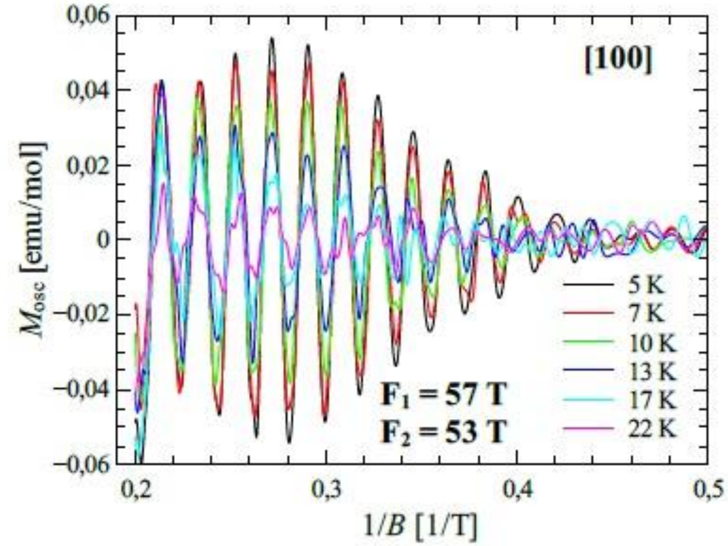
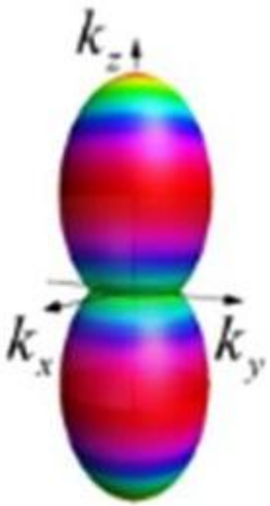


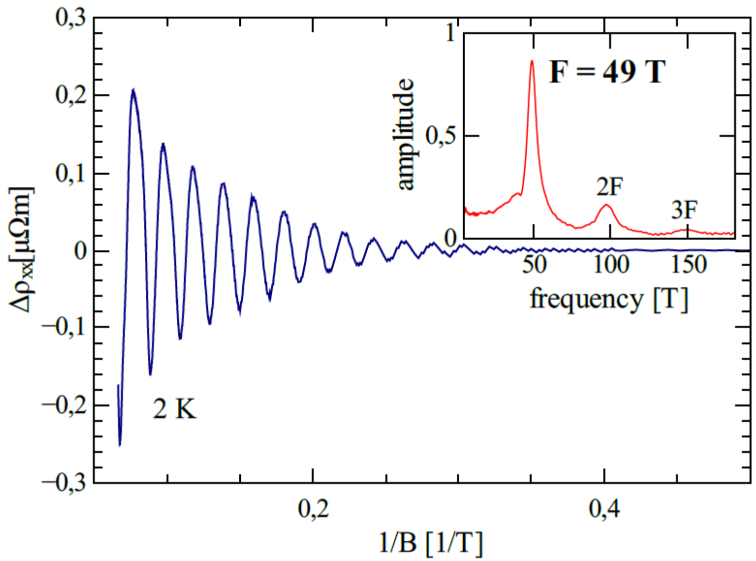
Cd_3As_2

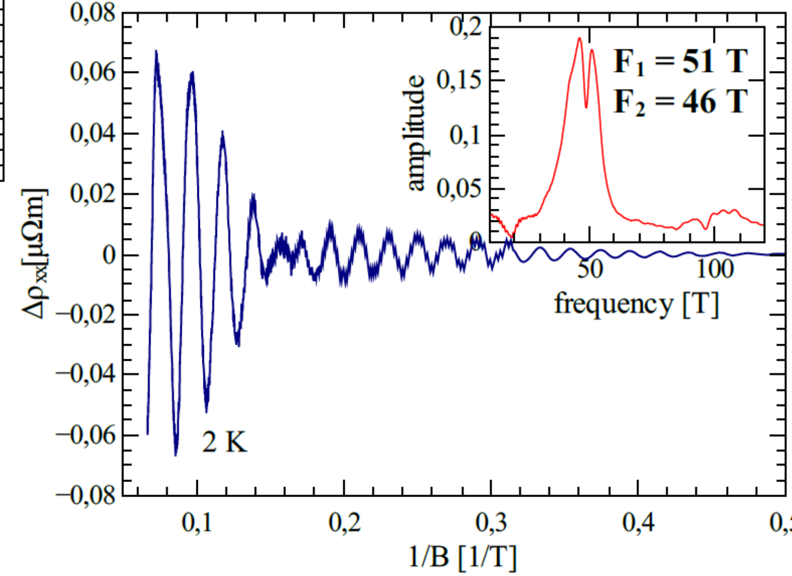
dHvA oscillations



Fermi surface of Cd_3As_2







Two frequencies for some directions of B-field.

SdH oscillations

our group:

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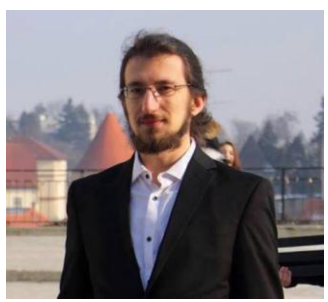
Doc. Dr. Sc. Mario Novak

Bruno gudac



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Thanks for the attention.

Questions?

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Hrvatska zaklada za znanost

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