Anomalous Hall effect and the anomalous Nernst effect in Weyl semimetal CeAlSi

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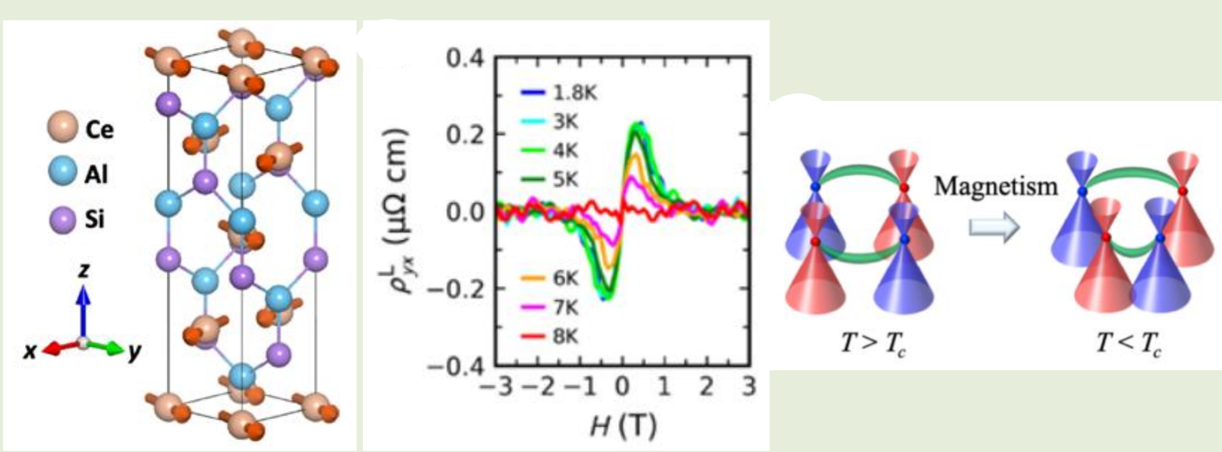
Abstract

In this work, we investigated the anomalous Hall effect (AHE) and the anomalous Nernst effect (ANE) for ferromagnetic Weyl semimetal CeAlSi. The resultant anomalous Hall conductivity (σ_{ij}^{A}) was either positive or negative depending upon orientation of the applied magnetic field (B), namely (σ_{yz}^{A}) for $B \parallel a$ is negative while (σ_{xy}^{A}) for $B \parallel c$ is positive, where a and c denote the crystallographic axes. The sign change of between σ_{xy}^{A} and σ_{yz}^{A} was attributed (using density functional theory calculations) to the reconstruction of the band structure under the variation of the spin orientation. In a system where humps in the AHE are present and scalar spin chirality is zero, we show that the k-space topology plays an important role to determine the transport properties at both low and high temperatures. The anomalous contribution has been also observed in the Nernst conductivity (α_{xy}^{A}/T) measured along $B \parallel c$ axis. α_{xy}^{A}/T turns out to be sizeable in the magnetic phase and above T_C slowly decreases with temperature. . To explain the temperature dependences of σ_{xy}^{A} and α_{xy}^{A}/T in paramagnetic phase, we introduce a single band toy-model including a non-zero Berry curvature in the vicinity of a Weyl node. A decisive factor appears to be a small energy distance between the Fermi level and a Weyl point

Introduction

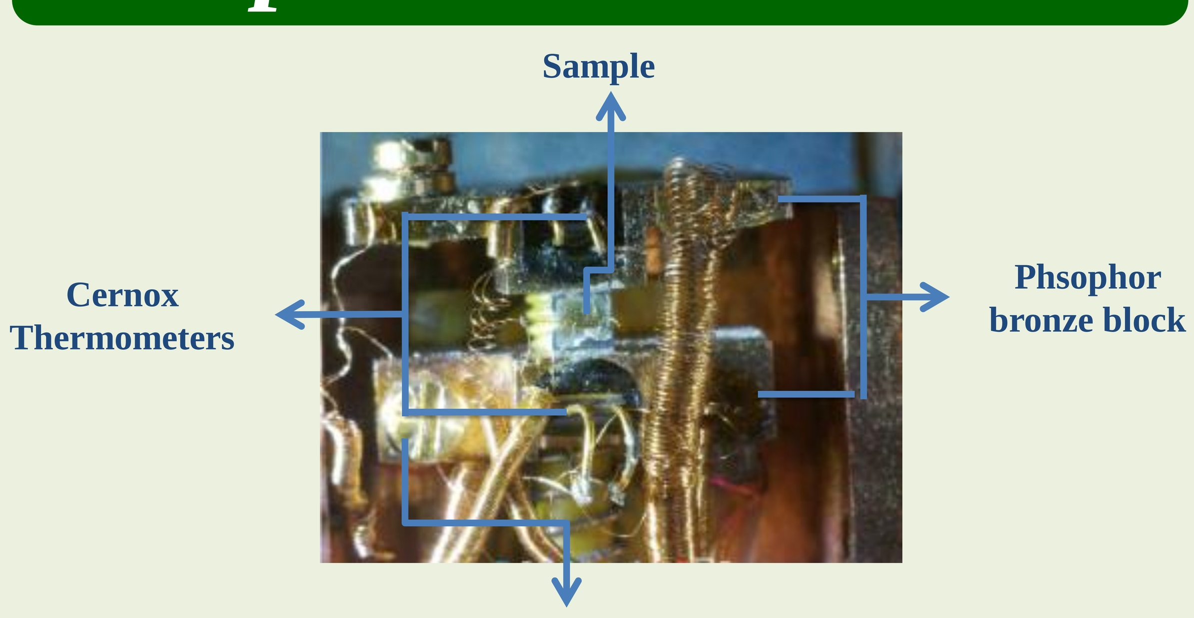
- In Weyl semimetals (WSMs), the modification of momentum space topological properties leading to host emergent response such as the topological Hall effect (THE) and the sign change of anomalous Hall effect
- The CeAlSi is a ferromagnetic Weyl semimetal below ***T_C < 8.5 K.***



- Weyl nodes has been generated due to the lack of inversion symmetry as well the time reversal symmetry and their presence has been reported in the below and above T_C
- THE in this material were dubbed as Loop hall effect was attribute to the k-space topology.

- The presence of ferromagnetic spins, broken inversion symmetry and high spin orbit coupling is motivated us to study the anomalous transport properties in this material.

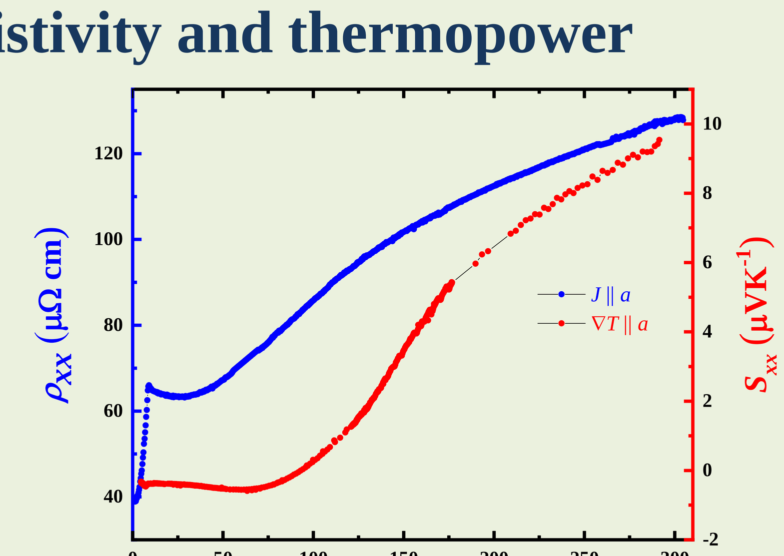
Experimental section



- To measure the thermo-electrical transport properties sample was clamp between two phosphor bronze block along with two Cernox thermometer and a resistive heater

Results

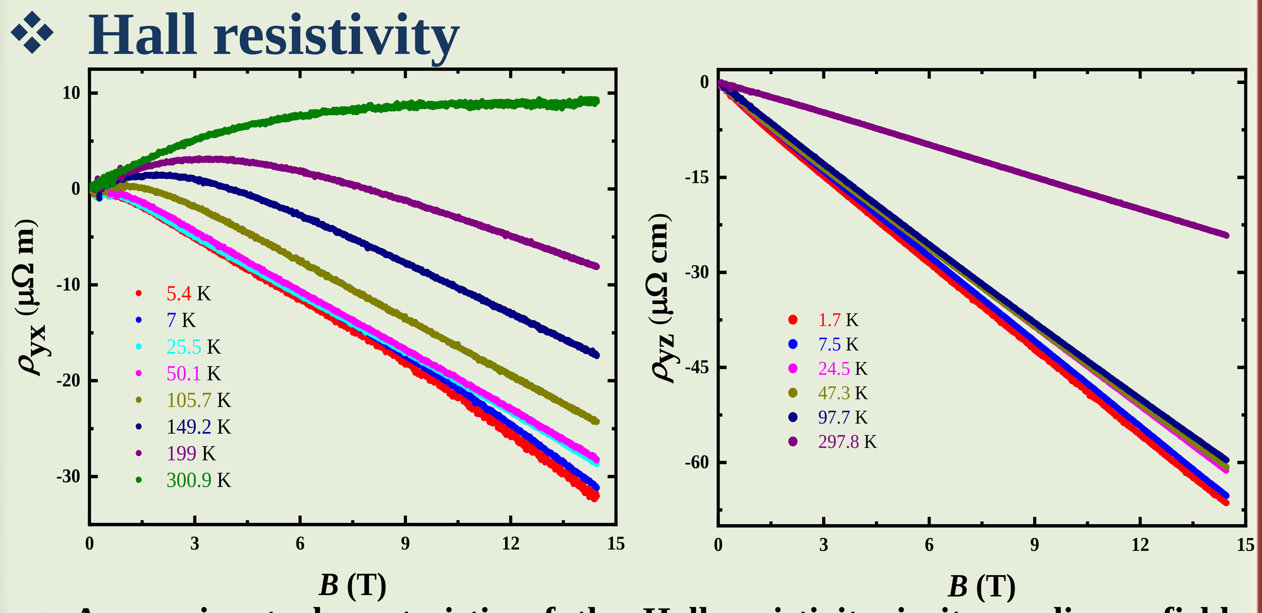
Resistivity and thermopower



- A critical ferromagnetic T_C~ 8.5 K and we observed negative S_{xx} < 100 K owing to the major role of electrons in the electrical transport at low temperatures

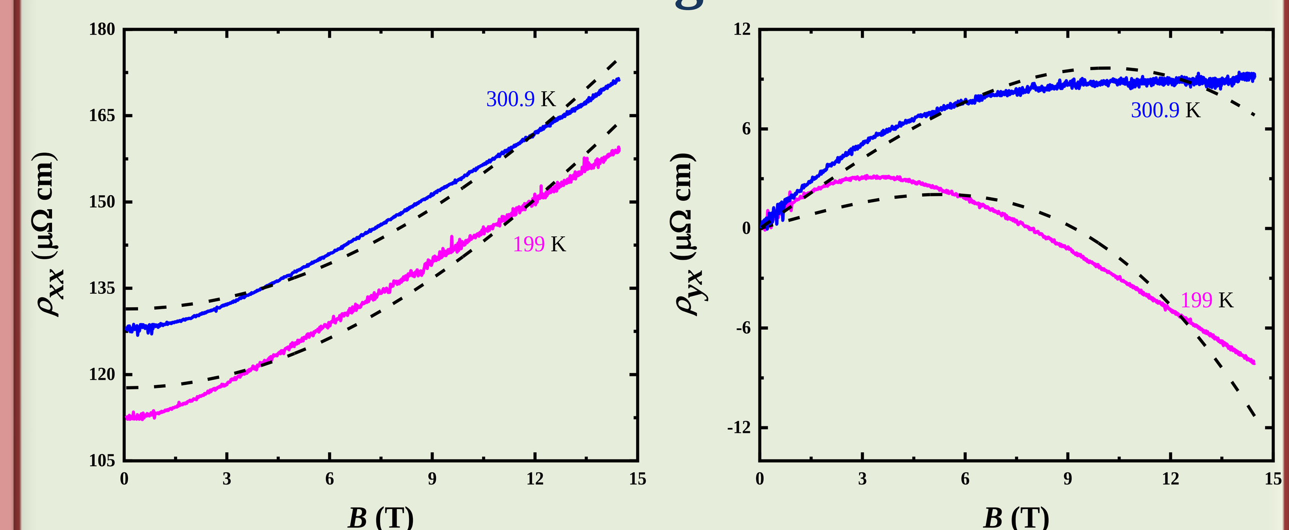
Electrical transport

Hall resistivity



- A prominent characteristic of the Hall resistivity is its nonlinear field dependence particularly pronounce for $B \parallel c$ axis. Although this type of behavior might be due to simultaneous contributions from different types of charge carriers?

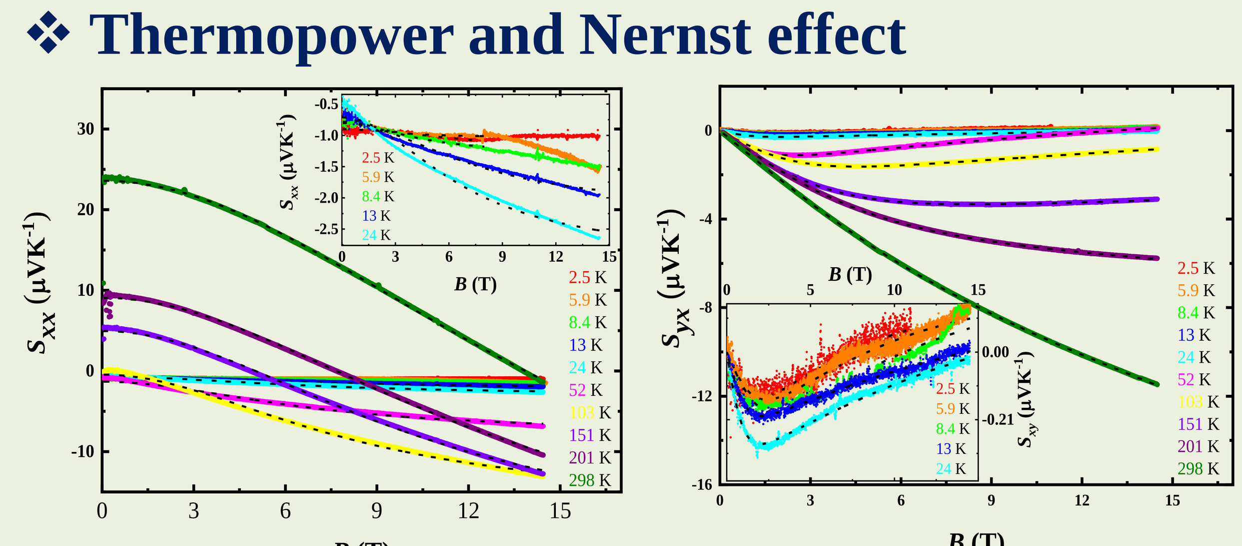
Non-anomalous Fitting



- A likely cause for a non-linear behavior of the Hall resistivity in CeAlSi is a contribution from the AHE

Thermoelectrical transport

Thermopower and Nernst effect

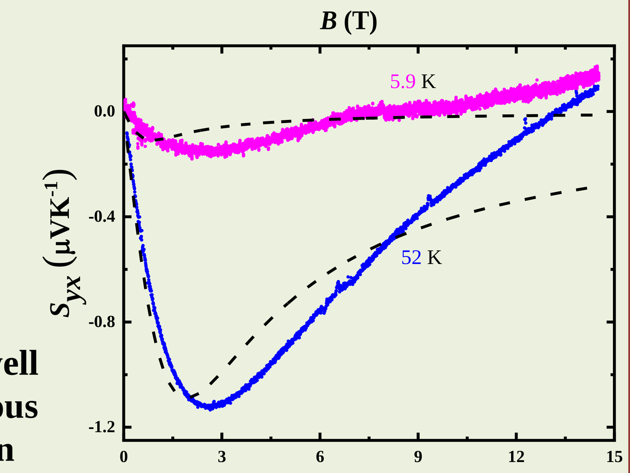


$$S_{xx}(B) = S_{xx}^{0}\frac{1}{1+(\mu B)^2} + S_{xx}^{\infty}\frac{(\mu B)^2}{1+(\mu B)^2}$$

$$S_{yx} = S_{yx}^{N} + S_{yx}^{A}$$

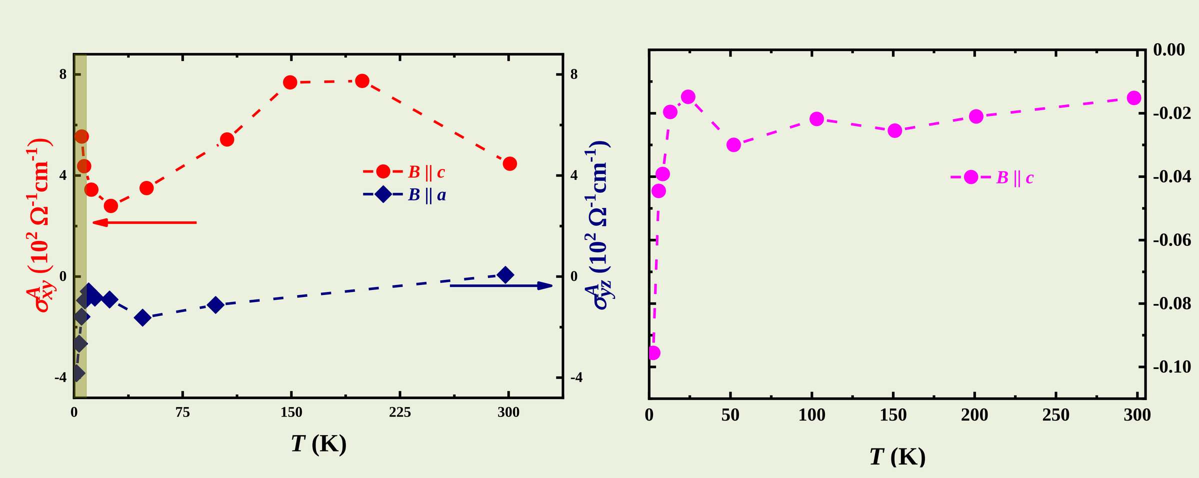
$$S_{yx}^{N} = S_{0}^{N}\frac{\mu}{1+(\mu B)^2}$$

$$S_{yx}^{A} = S_{yx}^{A}\, tanh(B/B_s)$$



- The Nests data are very well approximated when the anomalous component is taken into consideration

Anomalous Hall and Nernst effect



- The anomalous Hall conductivity turns out to be positive for the magnetic field applied along the magnetically hard axis (σ_{xy}^{A} > 0) and negative for B parallel to the easy axis (σ_{yz}^{A} < 0)
- α_{xy}^{A}/T turns out to be sizeable in the magnetic phase and above T_C slowly decreases with temperature.

References

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3. A. P. Sakhya et al., ArXiv:2203.05440 (2022).
4. N. Nagaosa et al., Rev. Mod. Phys. 82, 1539 (2010)
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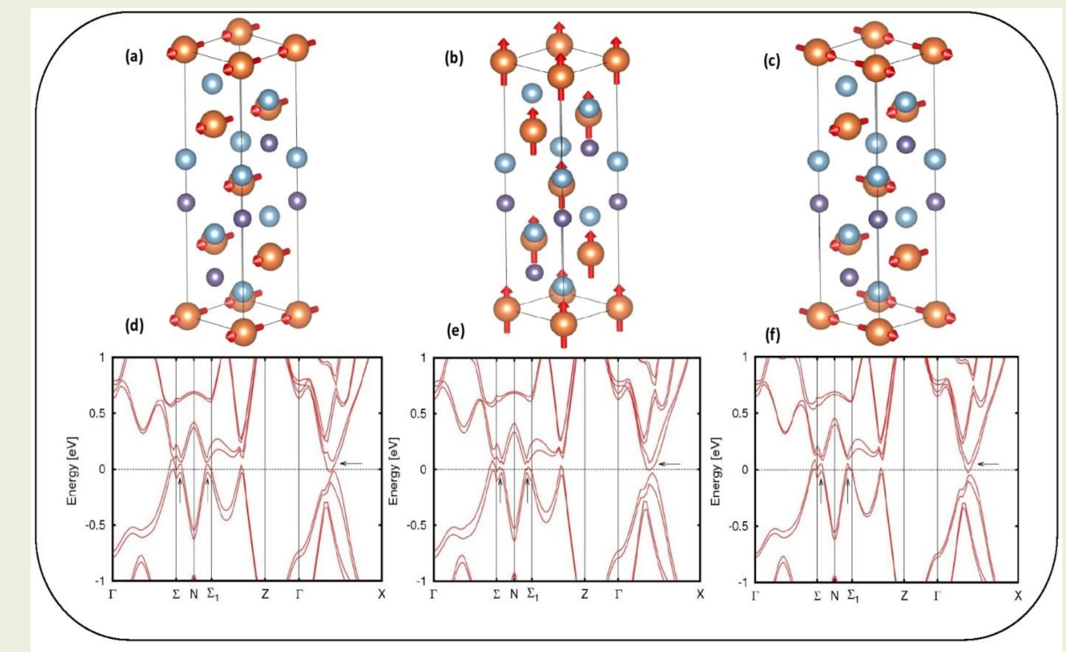
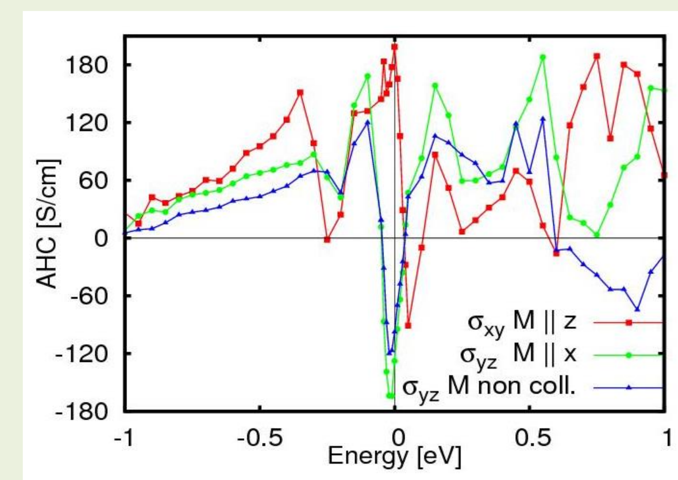
Theoretical calculations

Electronic structure



- Density functional theory calculations indicated the shift of Weyl points along the Γ-X direction induced by the reconstructions in the band structure driven by the magnetic configuration

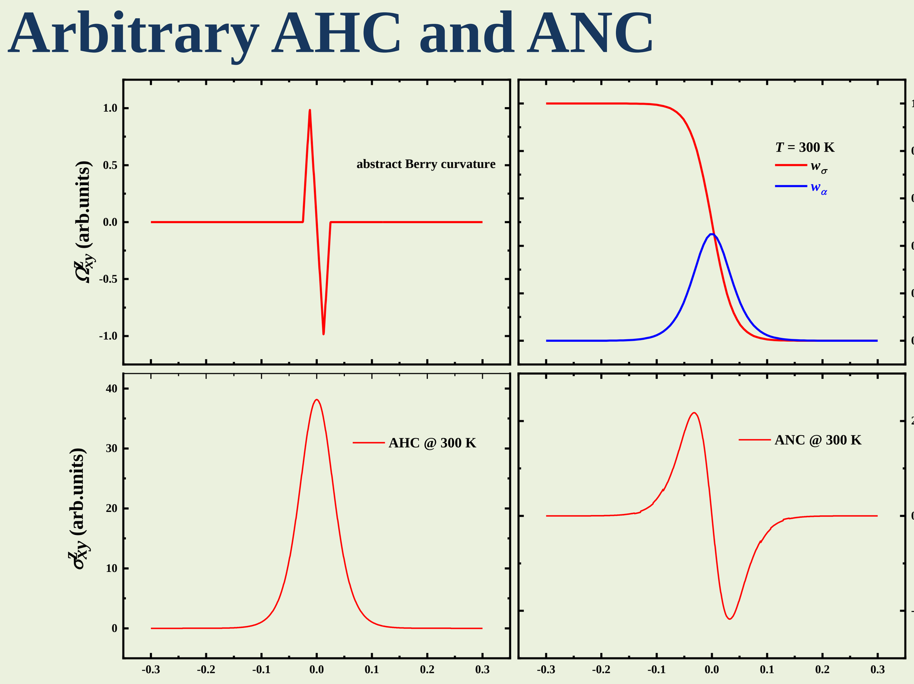
Anomalous Hall conductivity



- DFT calculations are line with the experimental results.

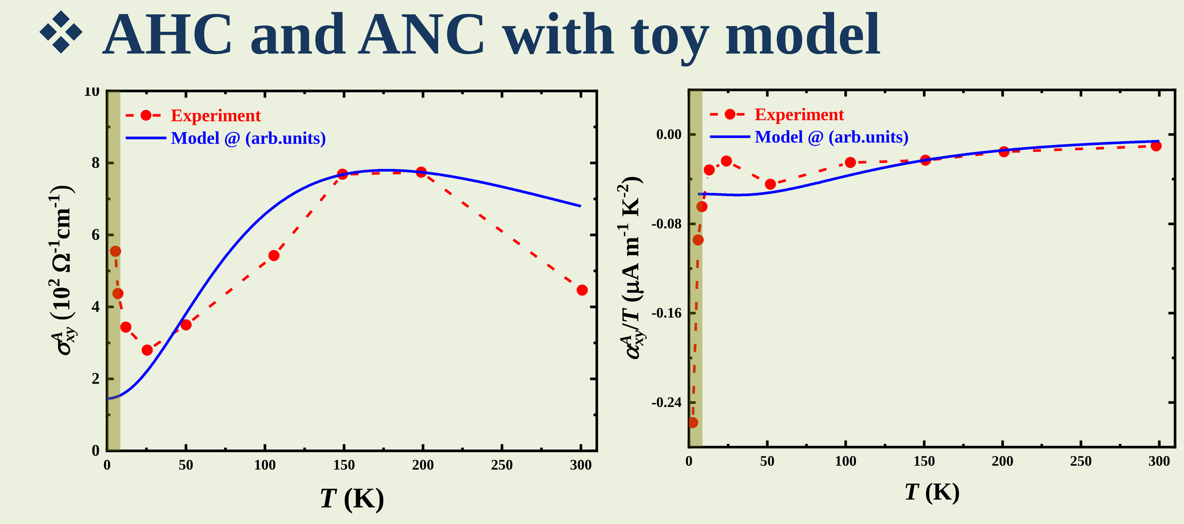
Toy Model

Arbitrary AHC and ANC



- Calculated anomalous Hall conductivity and the transverse thermoelectrical conductivity using non zero arbitrary Berry curvature and respective Weighting function

AHC and ANC with toy model



- In the paramagnetic phase the temperature dependence of σ_{xy}^{A} as well as the respective Nernst conductivity (α_{xy}^{A}) can be well approximated using a simple model assuming the presence of a Weyl point in the vicinity of the Fermi level

Conclusion

- We studied the anomalous Hall and Nernst effects in the non-collinear Weyl semimetal CeAlSi from room to low temperature.
- The anomalous Hall conductivity turns out to be positive for the magnetic field applied along the magnetically hard axis (σ_{xy}^{A} > 0) and negative for B parallel to the easy axis (σ_{yz}^{A} < 0).
- The sign change of the AHE attribute to shift of Weyl points along the Γ-X direction and this shift is induced by the reconstructions in the band structure driven by the magnetic configuration.
- The appearances of large σ_{xy}^{A} and none vanishing α_{xy}^{A} in the paramagnetic phase indicate that the Fermi level in CeAlSi lies in the vicinity of the Weyl node.

Acknowledgements

This work was supported by the Foundation for Polish Science through the IRA Programme co-financed by EU within SG

European Funds Smart Growth | Republic of Poland | Foundation for Polish Science | European Union European Regional Development Fund

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