Методи засновані на квантових осциляціях

Quantum oscillations techniques

Quantum oscillations techniques are based on Landau quantization (Landau levels)

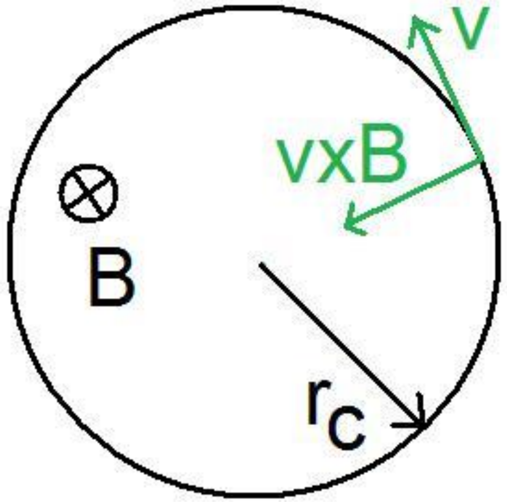
this produces oscillations in the many material properties:

- resistance (Shubnikov-de Haas effect),
- Hall resistance
- magnetic susceptibility (de Haas-van Alphen effect)

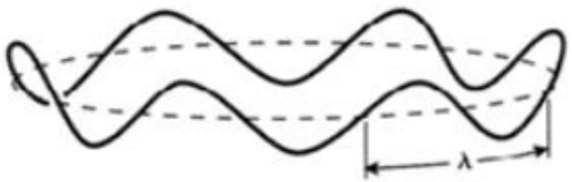
To read

- *J.M. Ziman*. Principles of the theory of solids (1972)
- …

Landau levels



$$\omega_c = \frac{eB}{m}$$



$$v = \omega_c r_c$$

$$2\pi r_c = n\lambda$$

$$p = mv = m\omega_c r_c$$

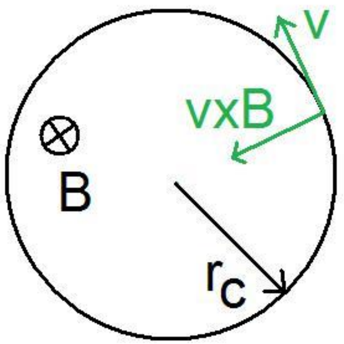
$$p = k\hbar = \frac{2\pi}{\lambda}\hbar$$

$$p = m\omega_c \frac{n\lambda}{2\pi} = m\omega_c \frac{n\hbar}{p}$$

$$E_n = \frac{p^2}{2m} = \frac{n}{2}\hbar\omega_c$$

$$E_n = \left(n + \frac{1}{2}\right)\hbar\omega_c$$

Landau levels



$$\hat{H} = \frac{1}{2m}|\hat{\mathbf{p}} - q\hat{\mathbf{A}}|^2 \qquad \mathbf{B} = \nabla \times \hat{\mathbf{A}} \qquad \hat{\mathbf{A}} = \begin{pmatrix} 0 \\ Bx \\ 0 \end{pmatrix}$$

$$\hat{H} = \frac{\hat{p}_x^2}{2m} + \frac{1}{2m}(\hat{p}_y - qB\hat{x})^2 + \frac{\hat{p}_z^2}{2m}$$

$$\hat{H} = \frac{\hat{p}_x^2}{2m} + \frac{1}{2}m\omega_c^2\left(\hat{x} - \frac{\hbar k_y}{m\omega_c}\right)^2 + \frac{\hat{p}_z^2}{2m}$$

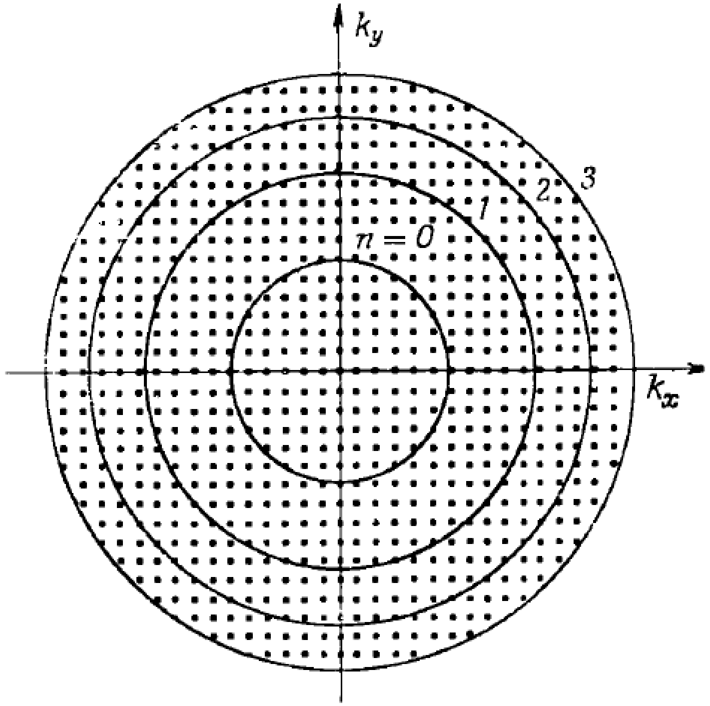
$$E_n = \hbar\omega_c\left(n + \frac{1}{2}\right) + \frac{p_z^2}{2m}$$

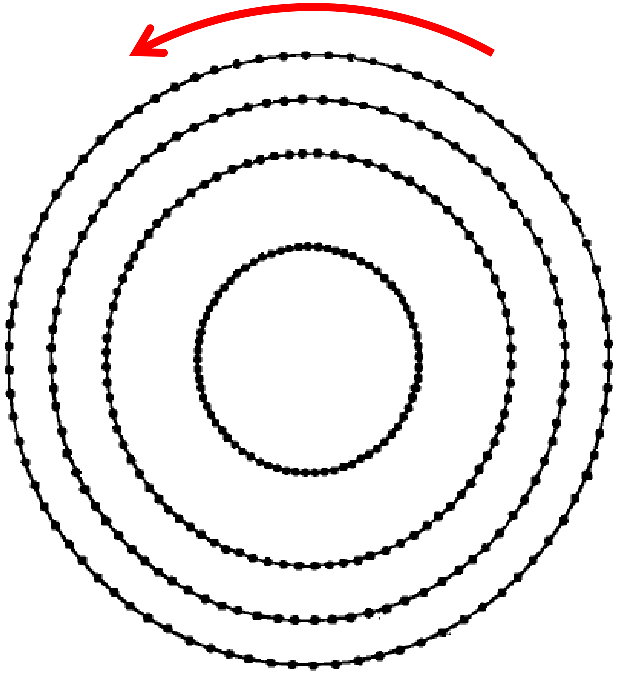
$$E_n = \left(n + \frac{1}{2}\right)\hbar\omega_c$$

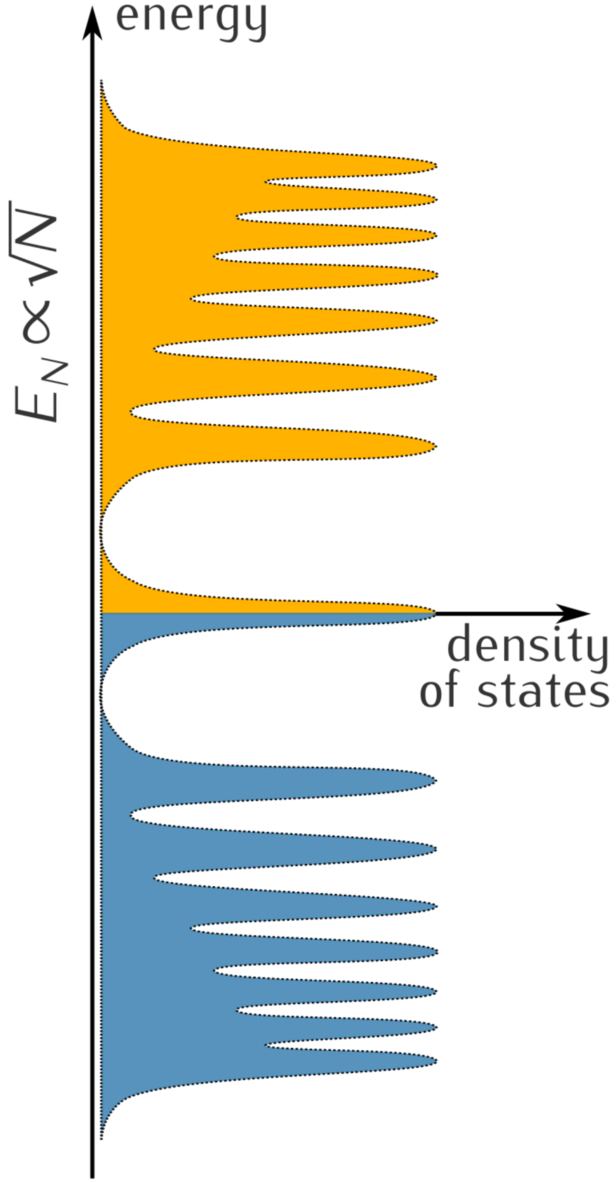
https://en.wikipedia.org/wiki/Landau_quantization

Landau levels

$$E_n = \left(n + \frac{1}{2}\right)\hbar\omega_c \qquad \omega_c = \frac{eB}{m}$$

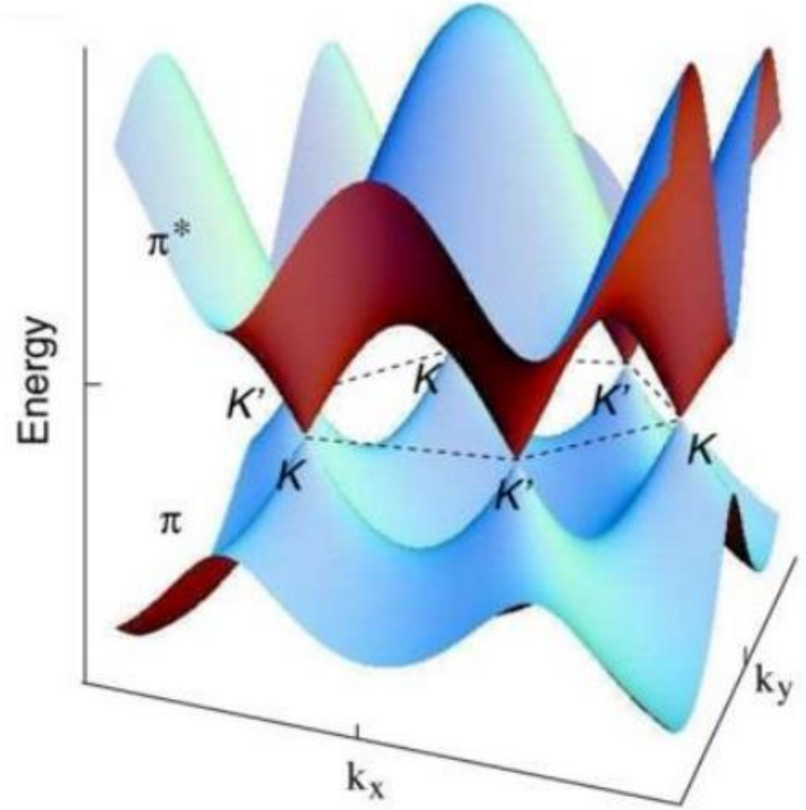


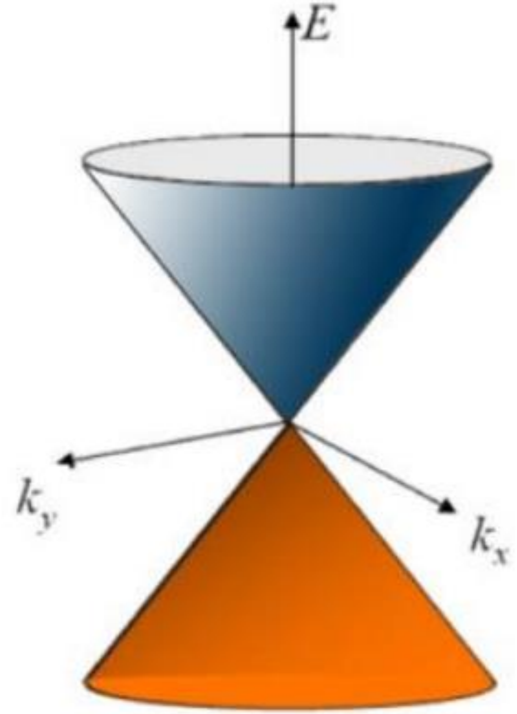


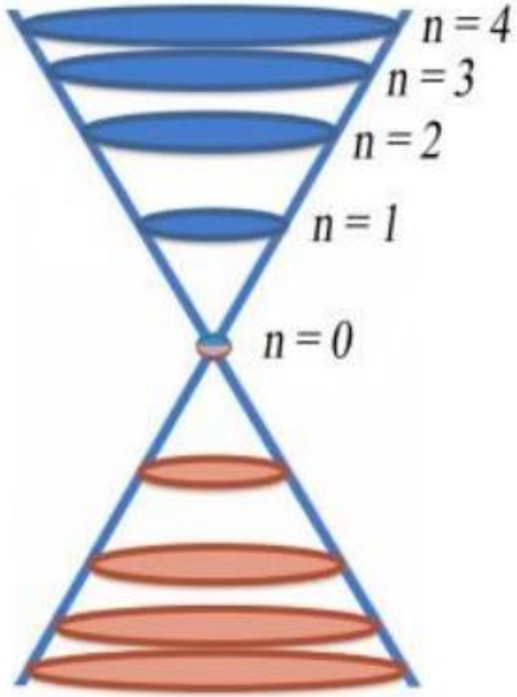


J.M. Ziman. Principles of the theory of solids (1972)

Landau levels in Graphene

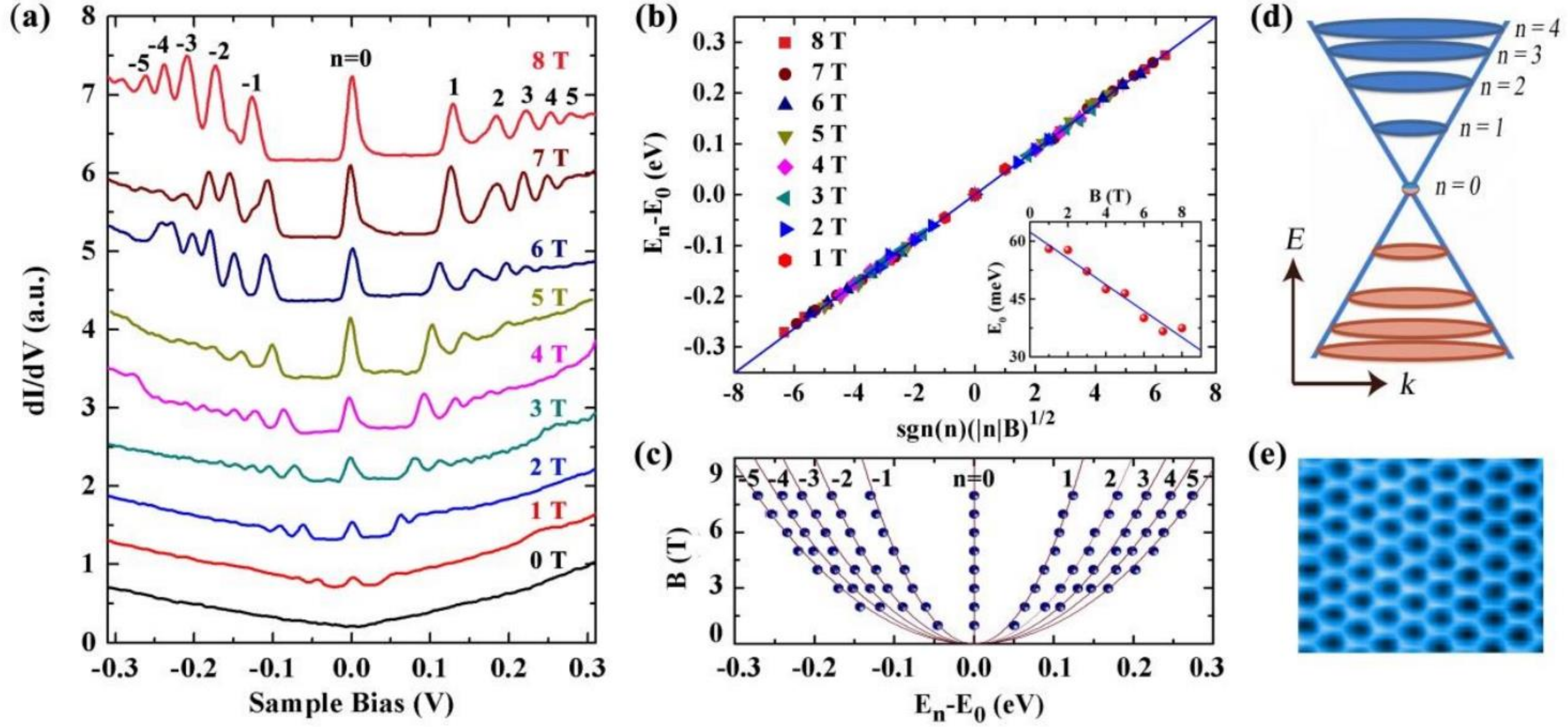






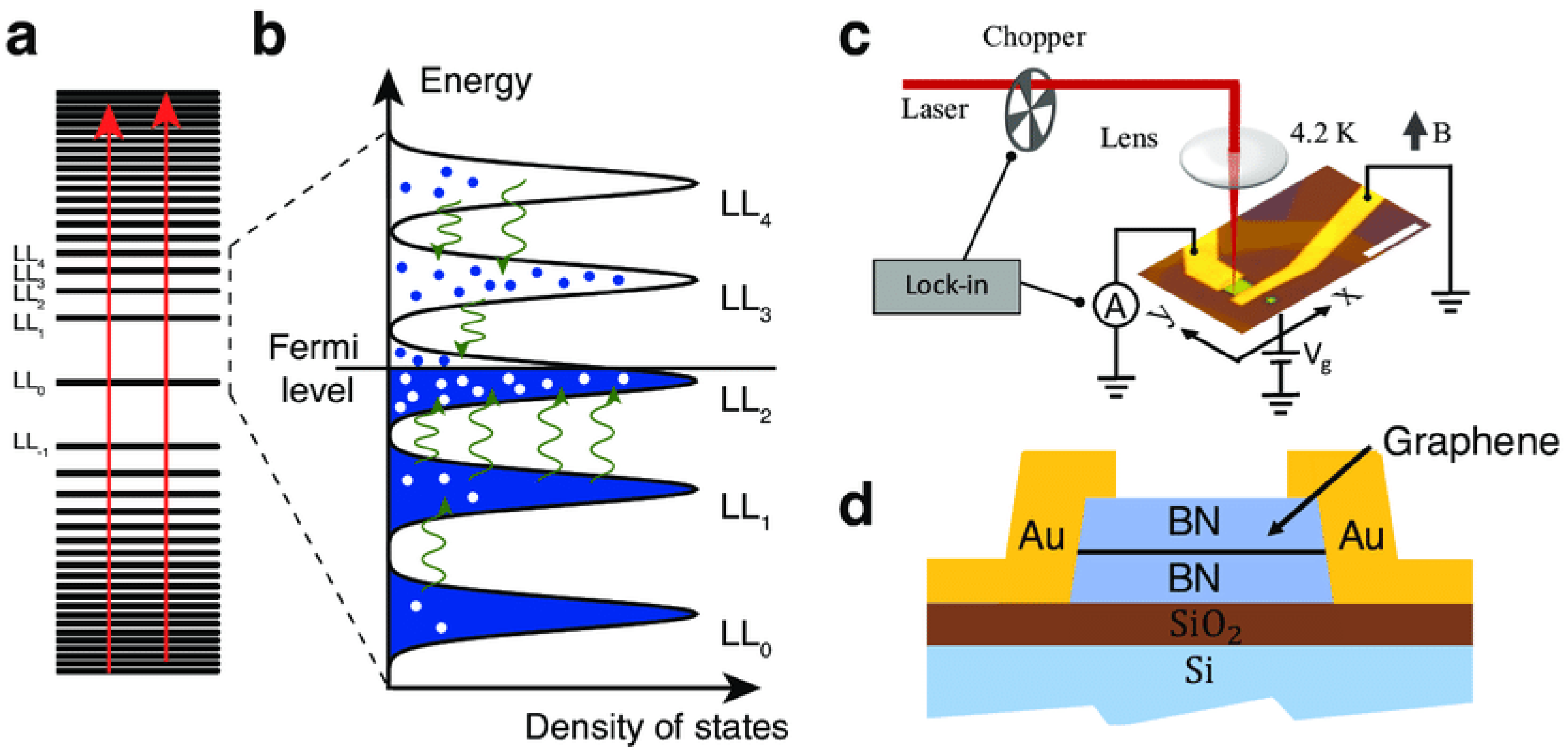
https://arxiv.org/ftp/arxiv/papers/1703/1703.04241.pdf

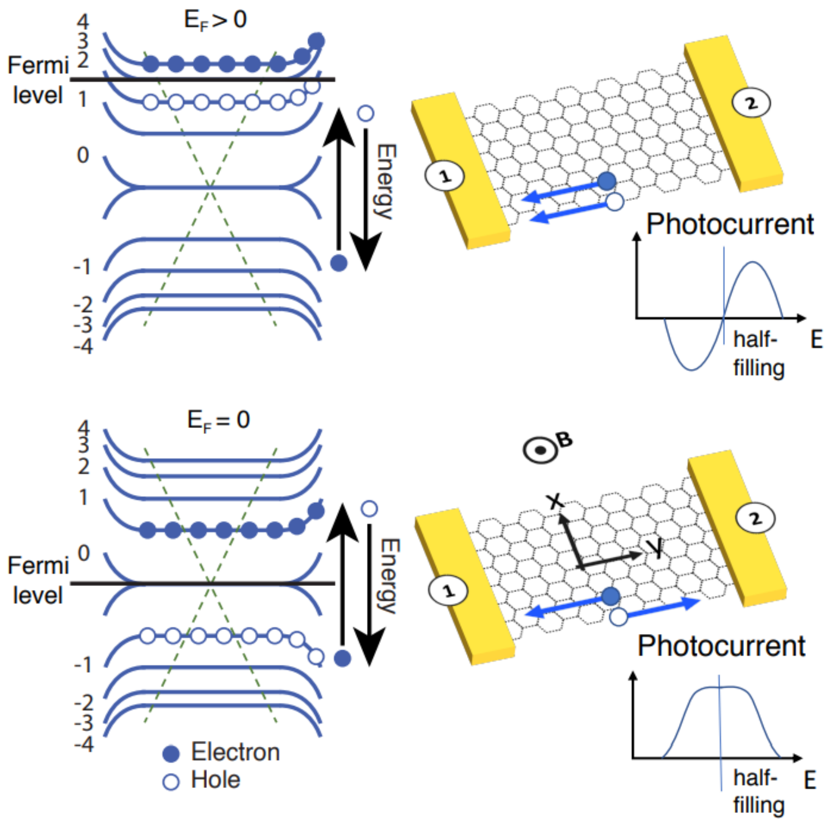
Landau levels in Graphene



https://arxiv.org/ftp/arxiv/papers/1703/1703.04241.pdf

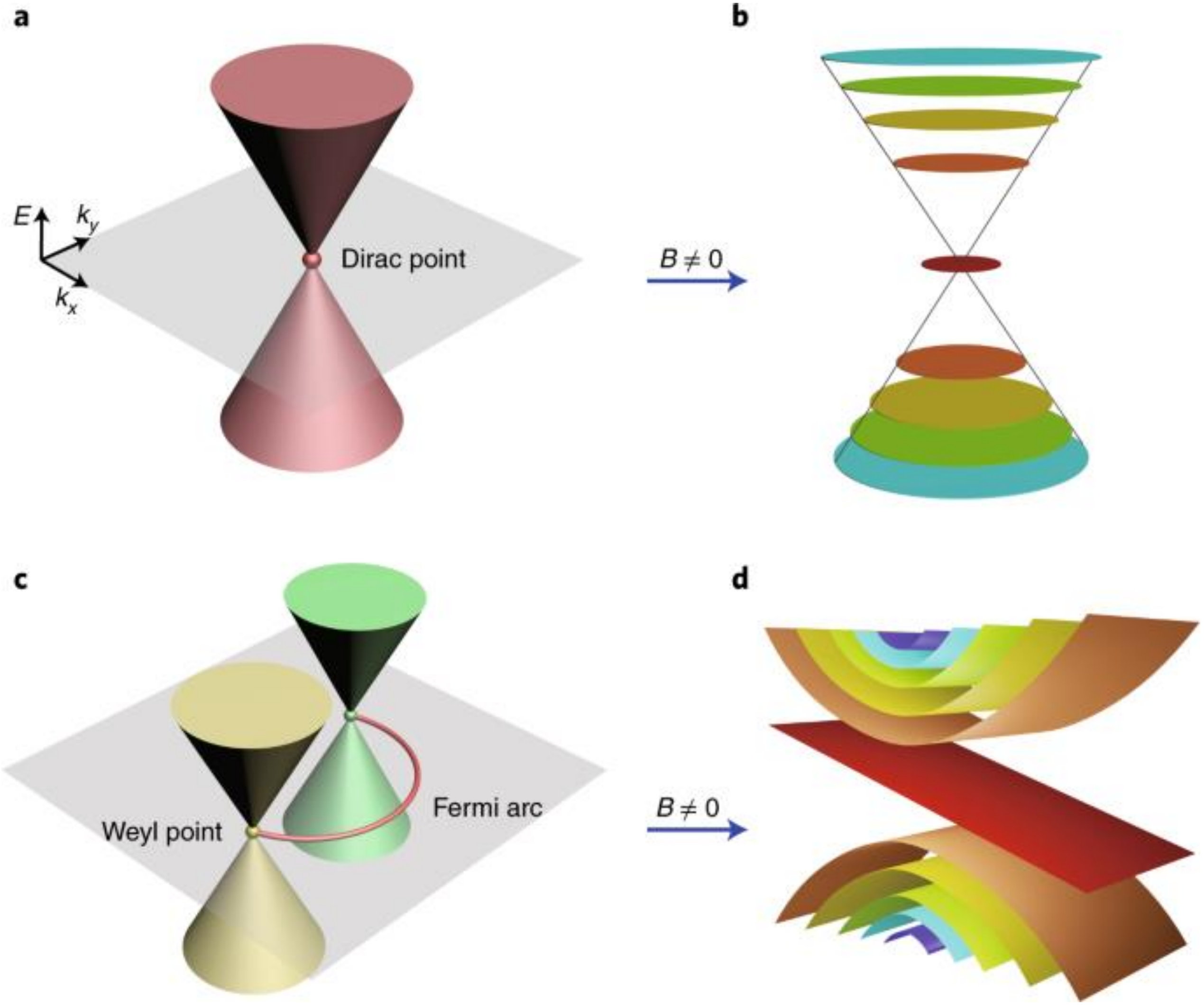
Landau levels in Graphene





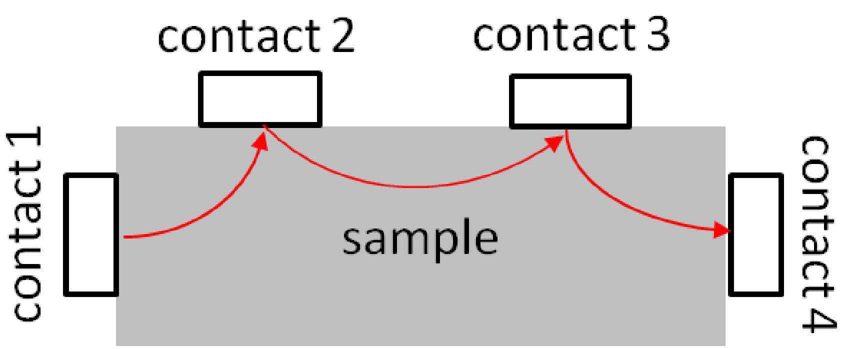
https://arxiv.org/abs/1903.01487

Audible Landau levels

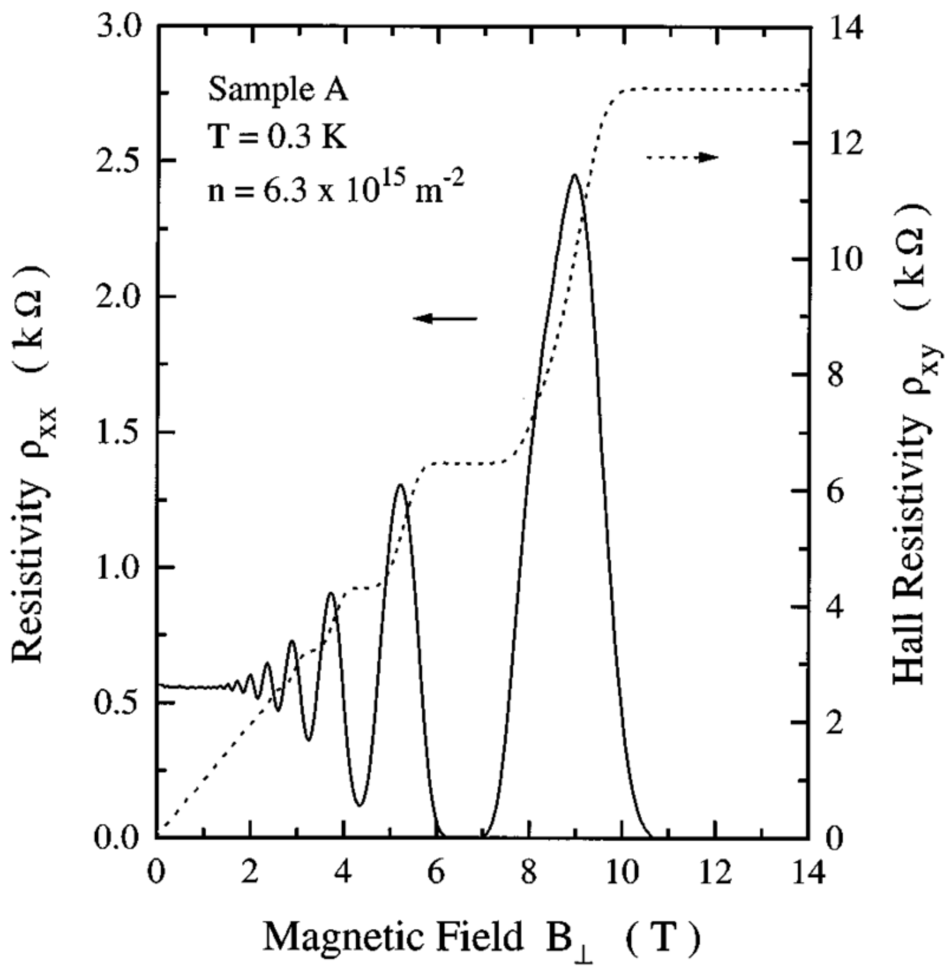


Zhang, B. Audible Landau levels. *Nat. Phys.* **15,** 307 (2019). https://doi.org/10.1038/s41567-019-0479-7

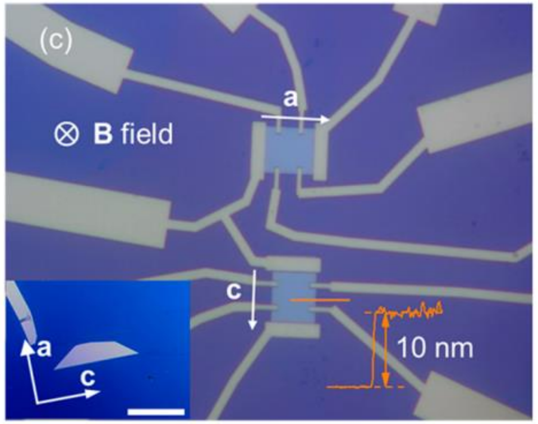
Shubnikov-de Haas effect

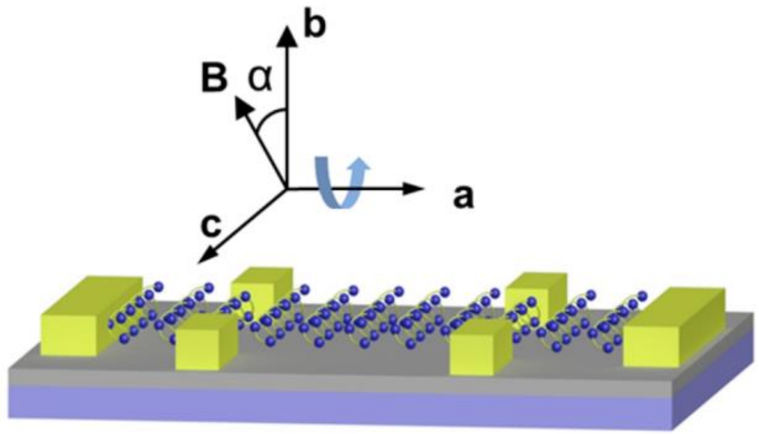


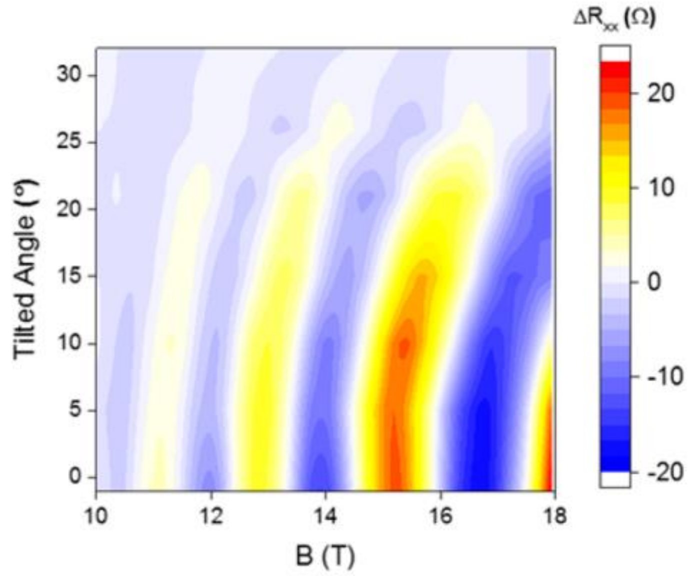
$$n_{2DEG} = \frac{2e}{h} \frac{1}{\Delta(1/B)}$$

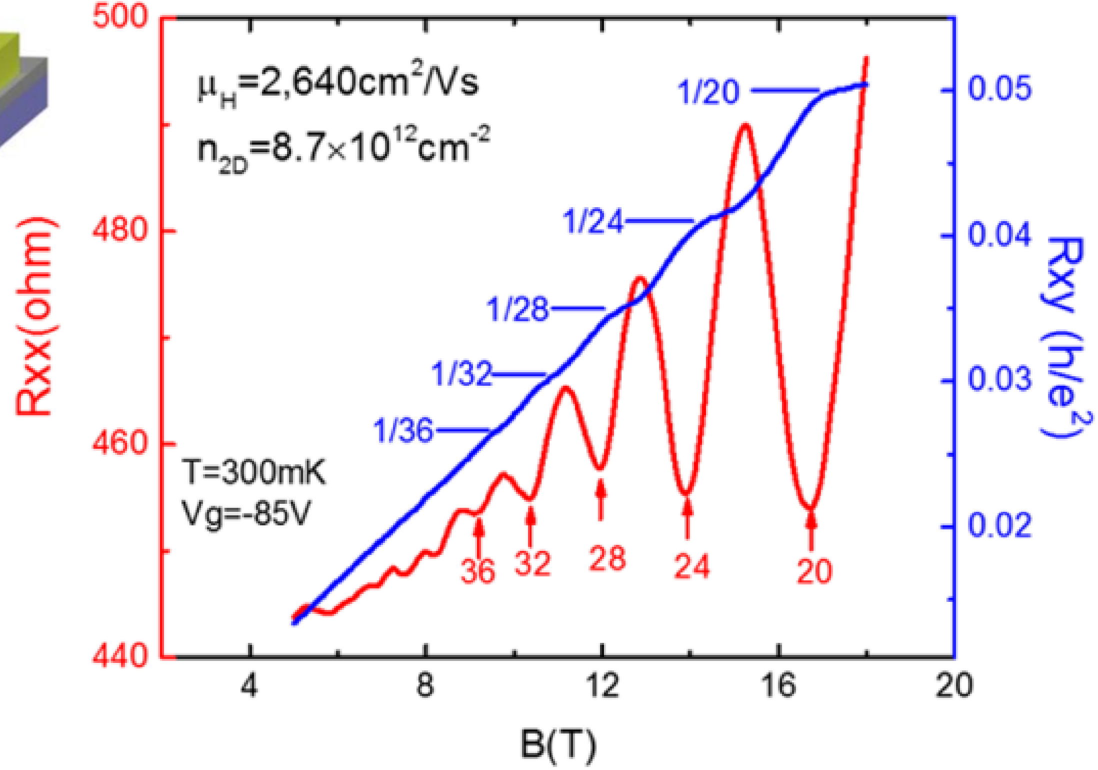


Quantum oscillations in Few-Layer Tellurene



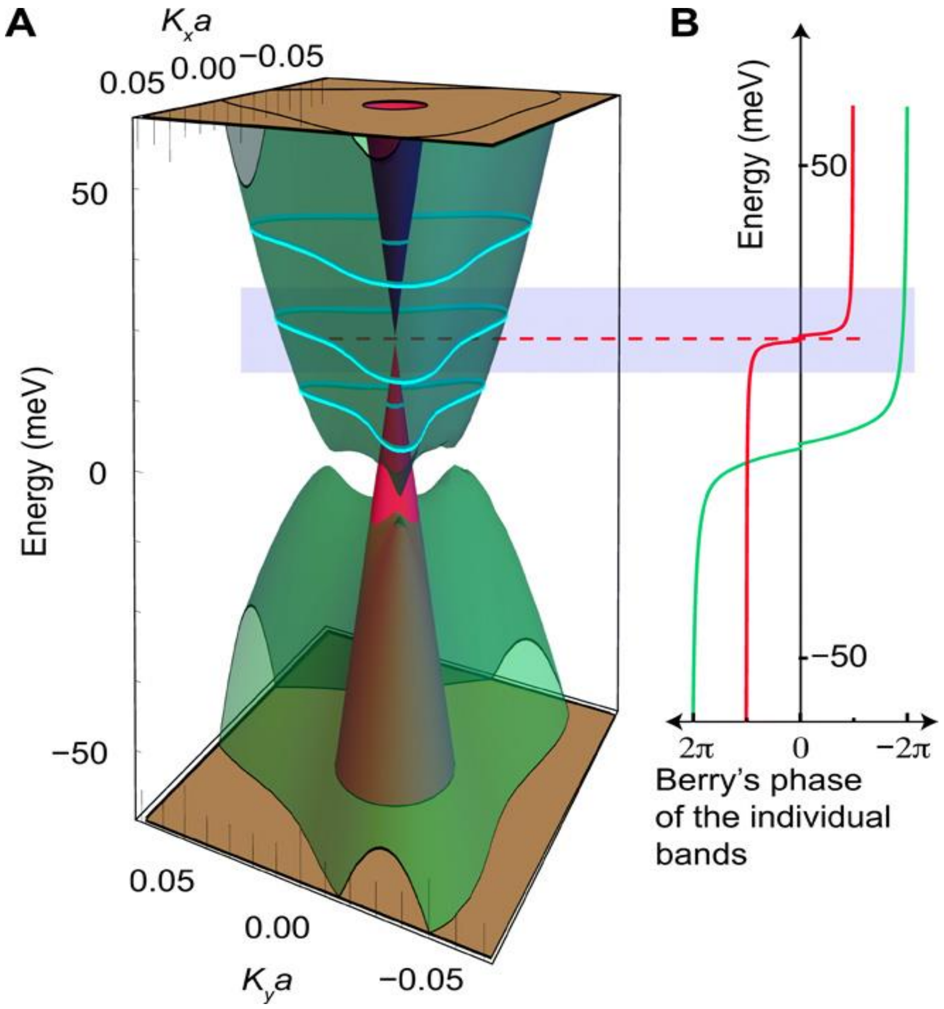


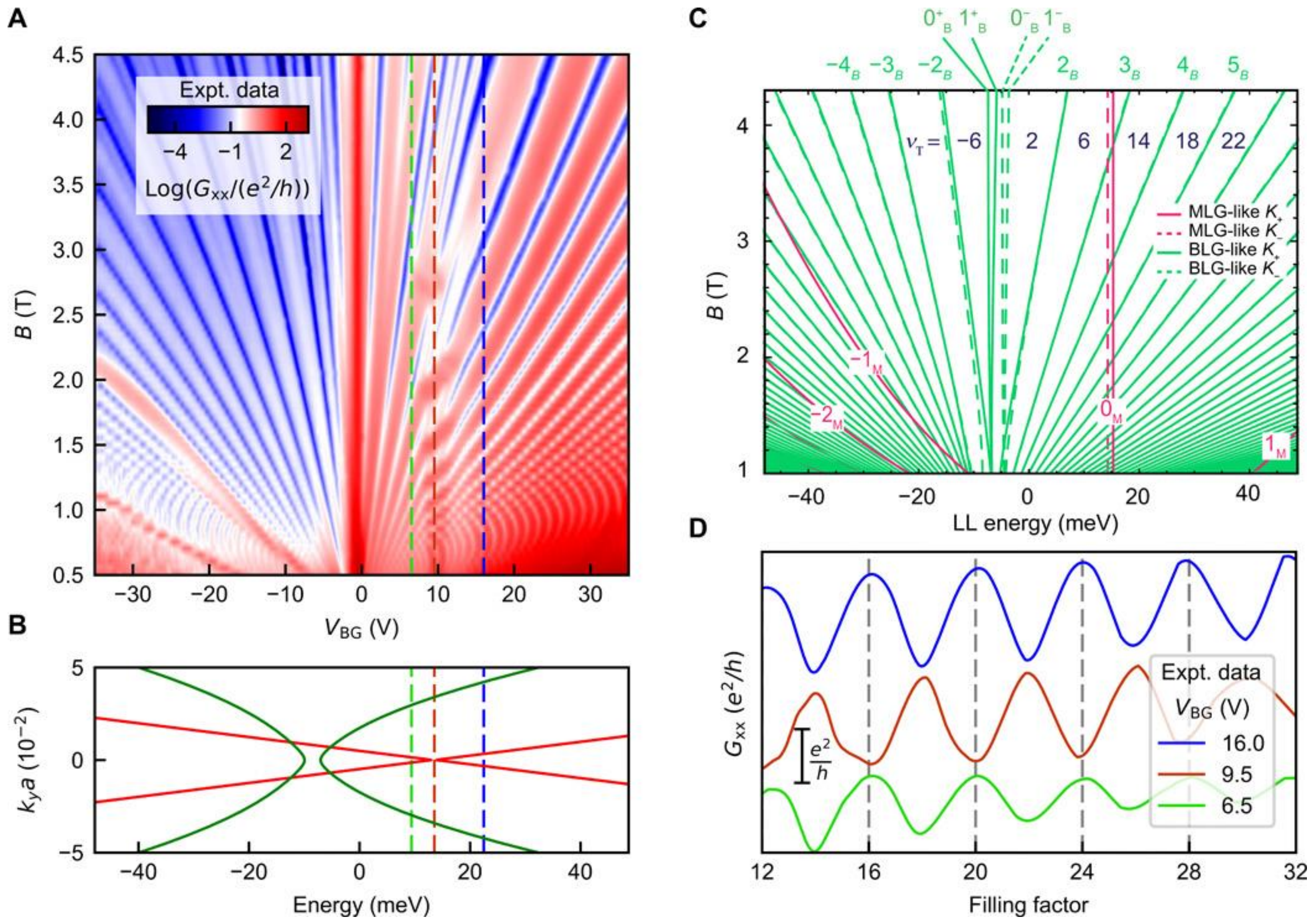




G. Qiu. Quantum Transport and Band Structure Evolution under High Magnetic Field in Few-Layer Tellurene.
https://engineering.purdue.edu/~yep/Papers/Nano%20Letters_Te_QHE_2018.pdf

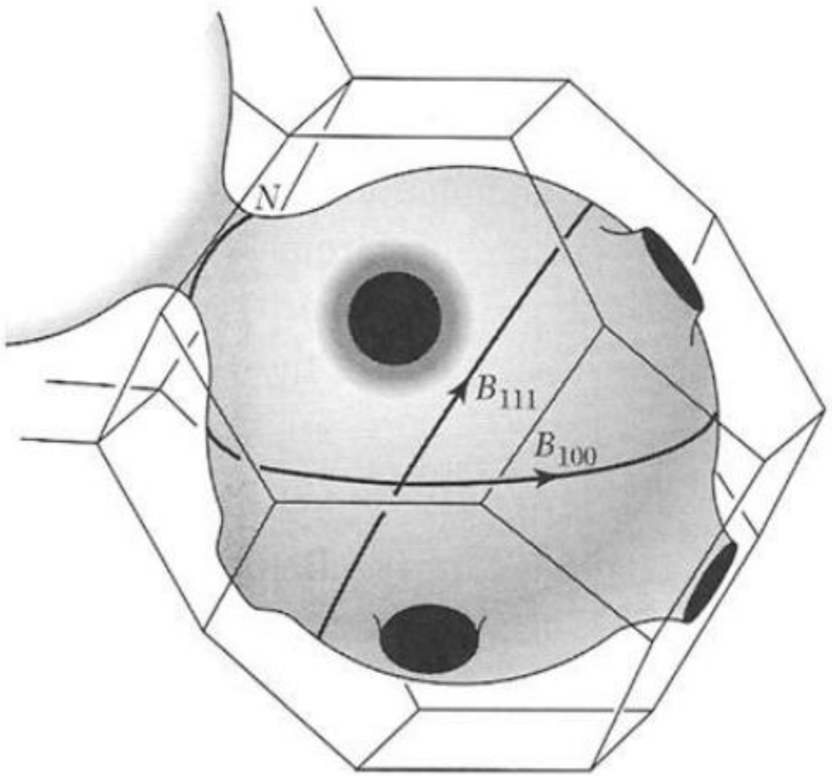
Nontrivial quantum oscillations

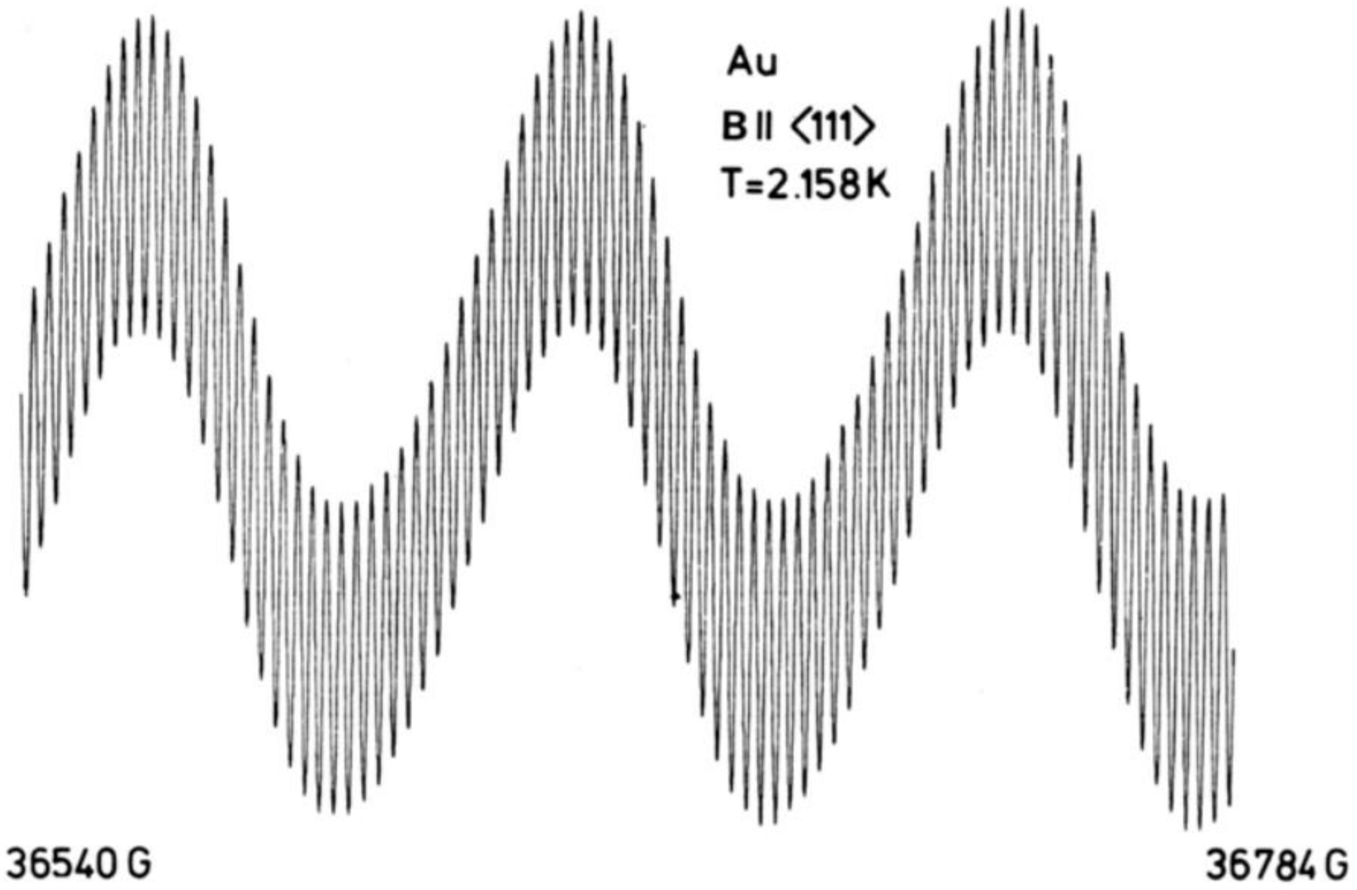




B. Datta. Nontrivial quantum oscillation geometric phase shift in a trivial band. https://www.science.org/doi/10.1126/sciadv.aax6550

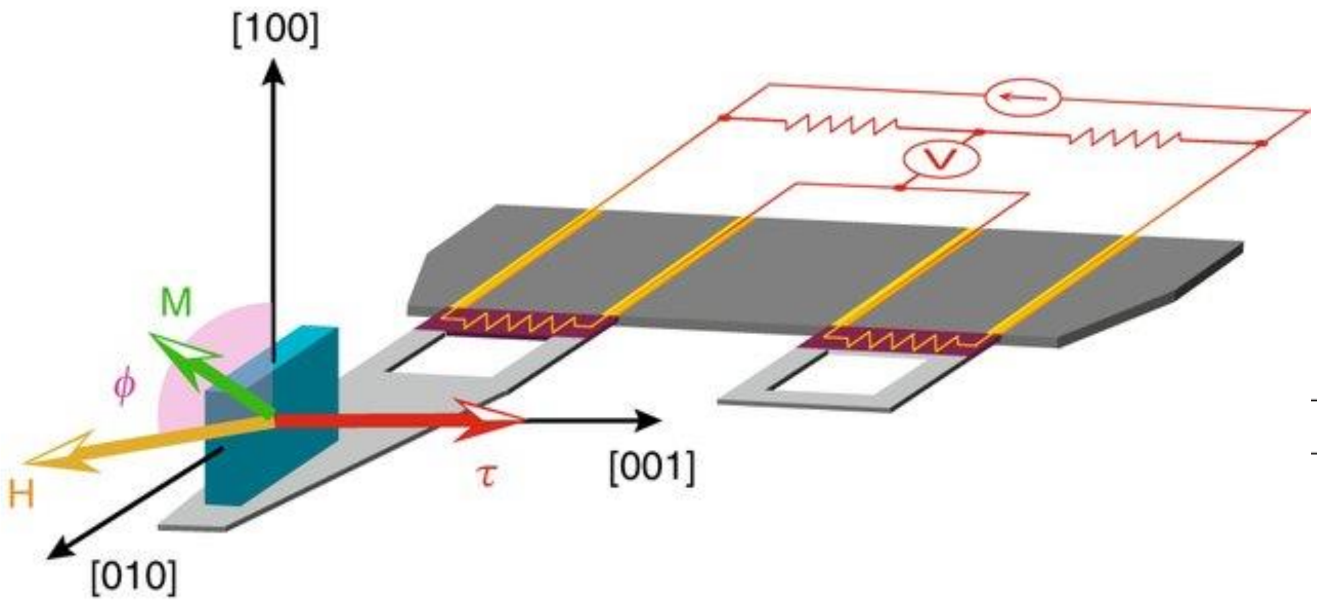
de Haas-van Alphen effect

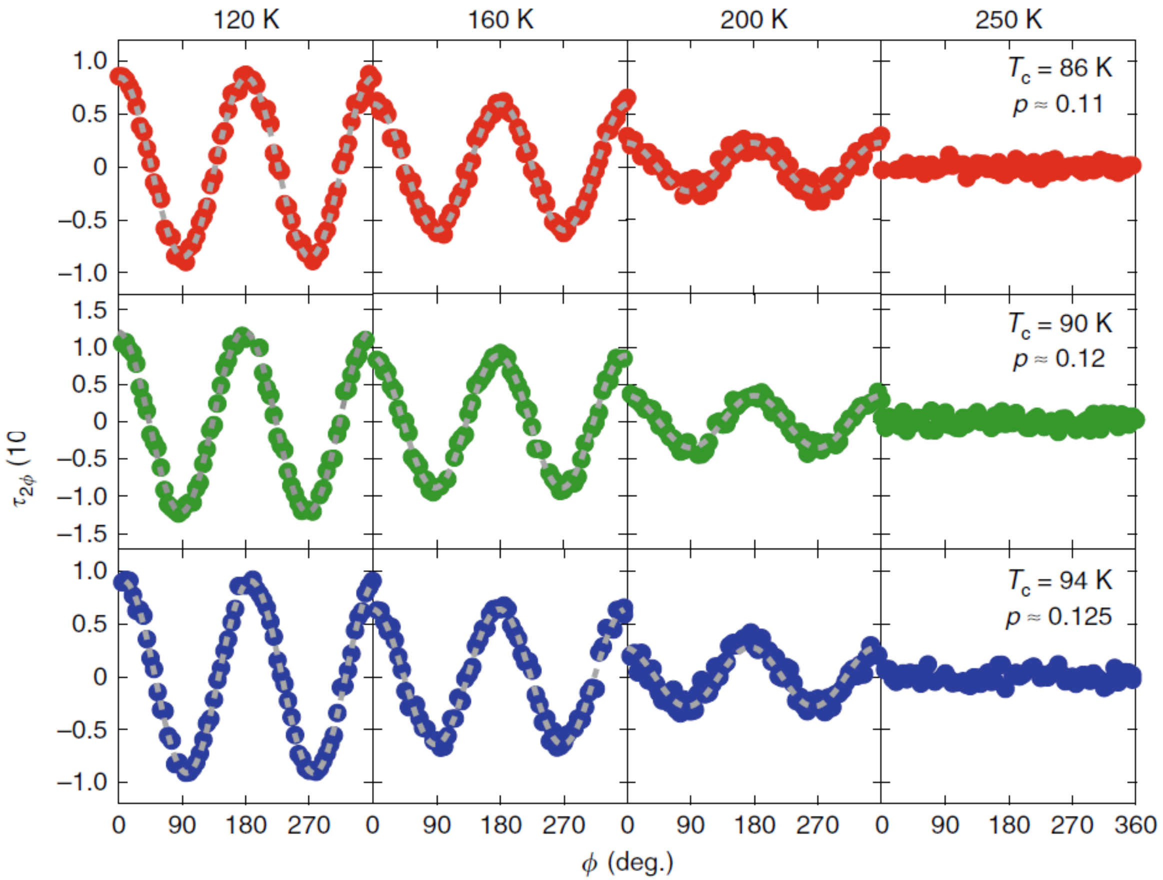




$$F = (\hbar/2\pi e)A_k$$

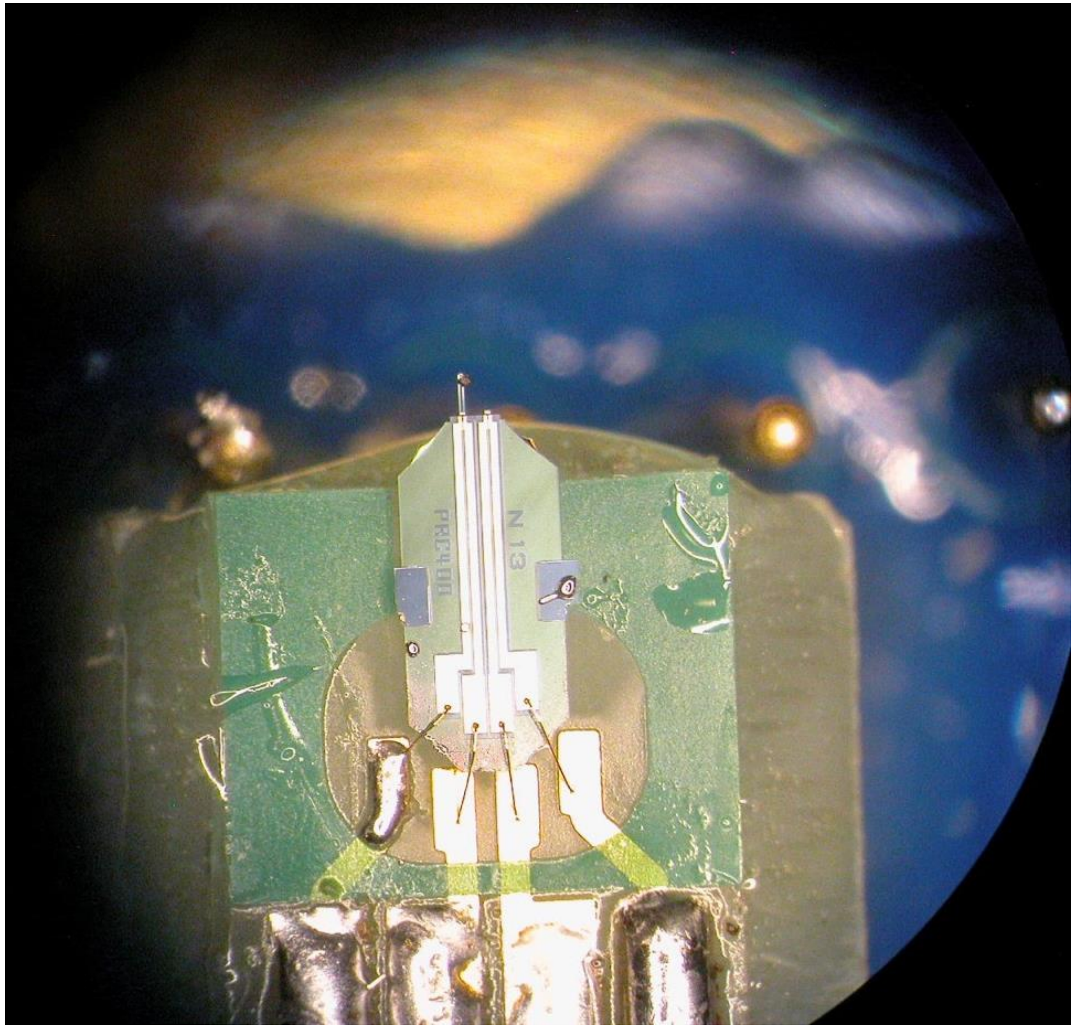
Torque Magnetometry

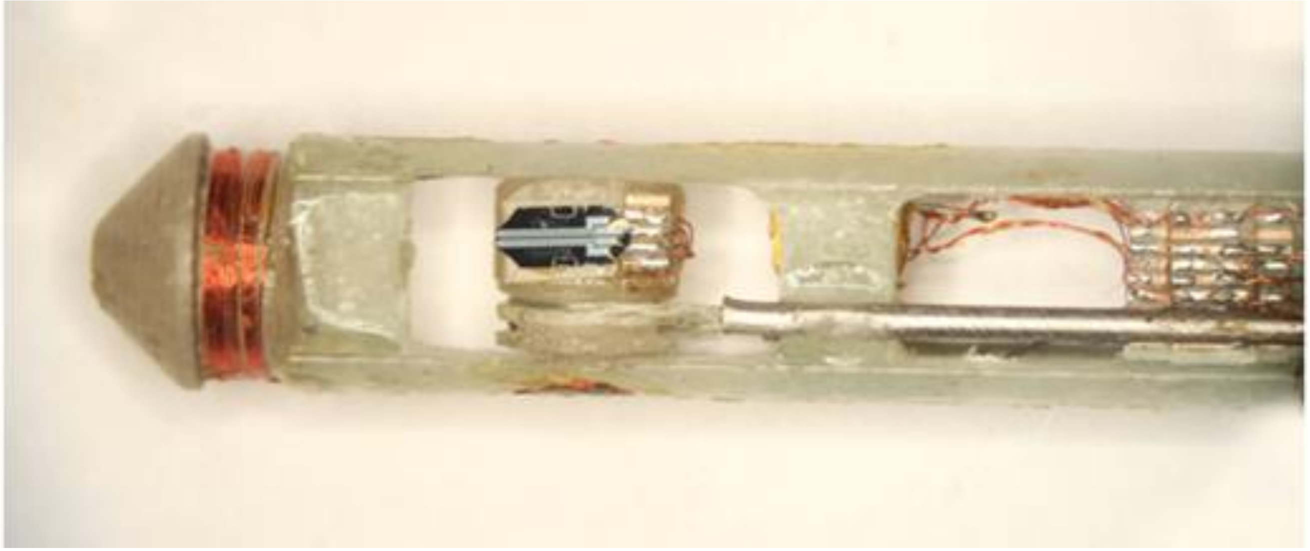


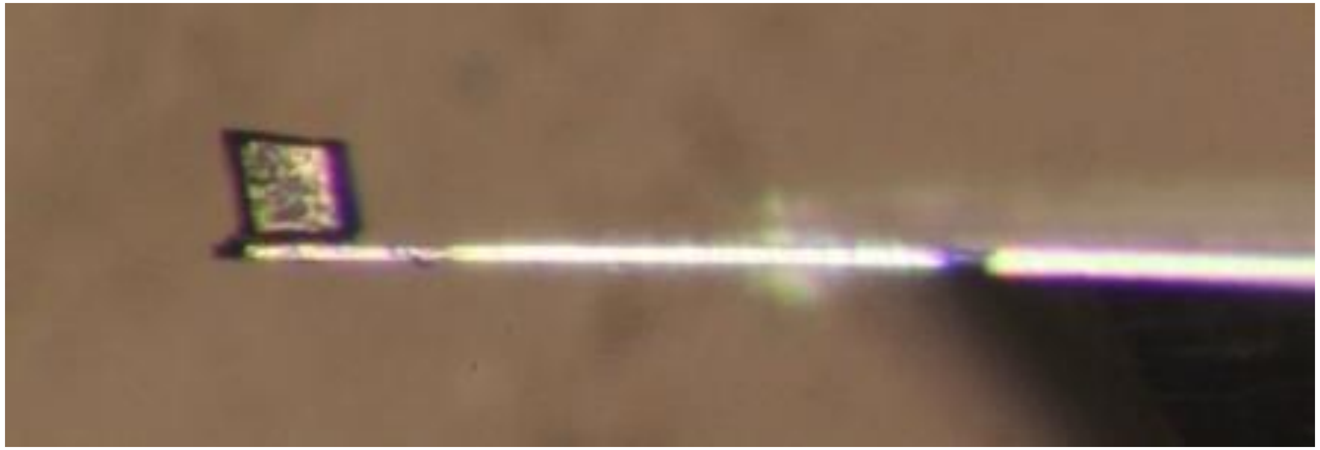


Diagonal nematicity in the pseudogap phase of HgBa2CuO4+δ *Nature Communications* 10, 3282 (2019)

Torque Magnetometry

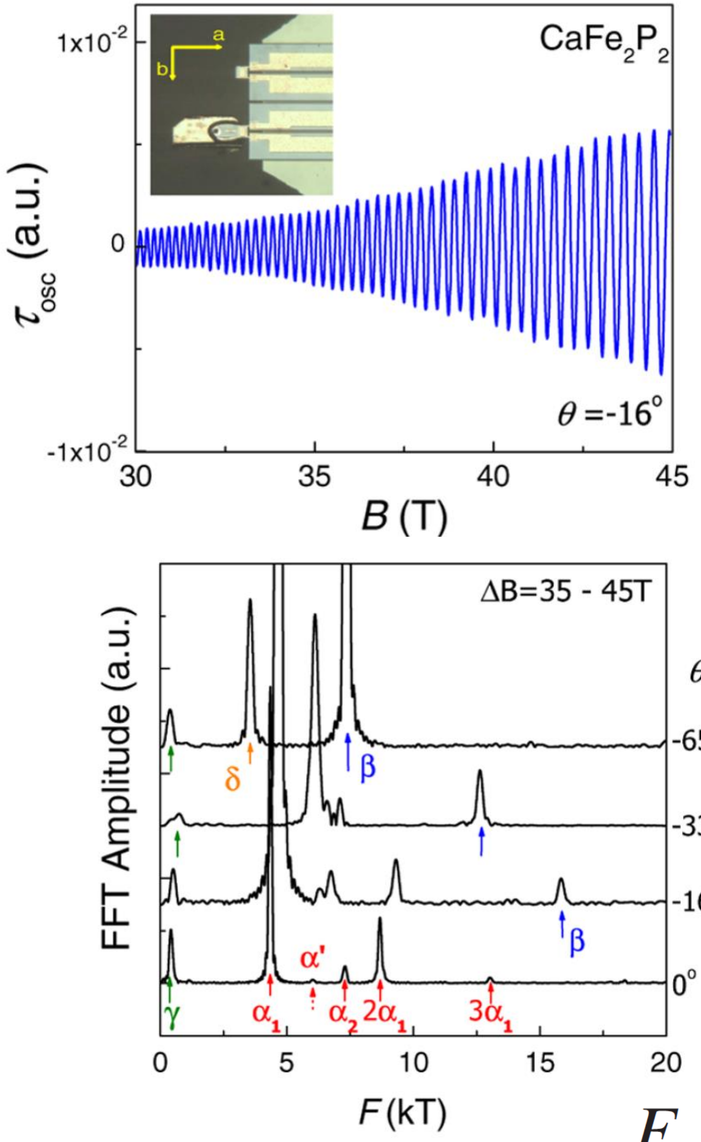


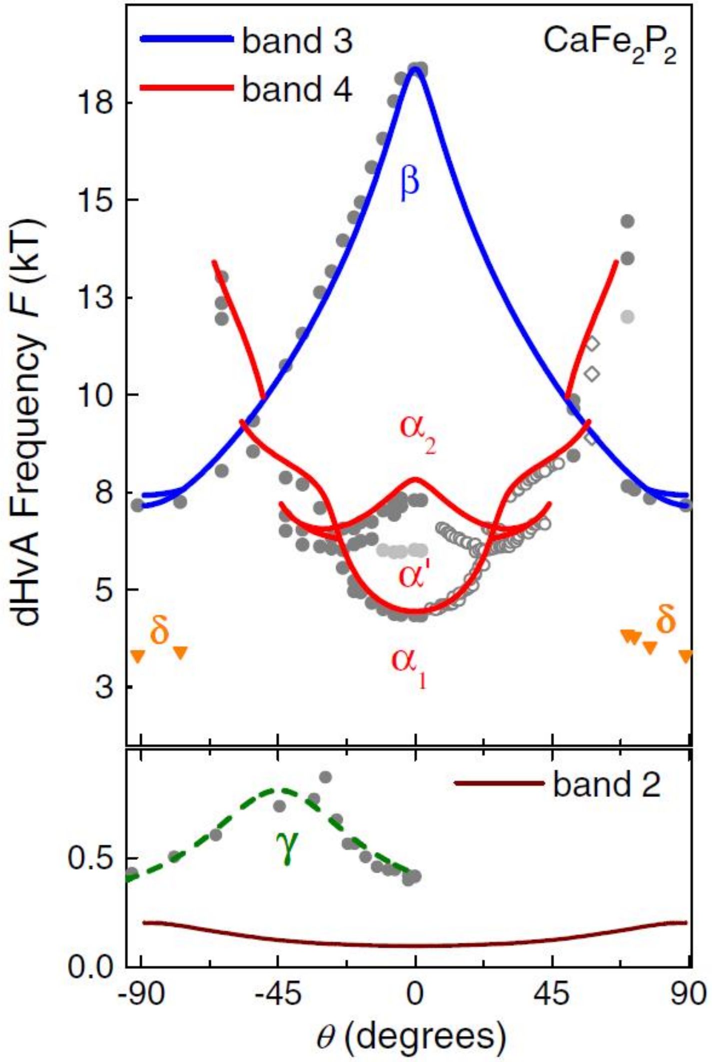


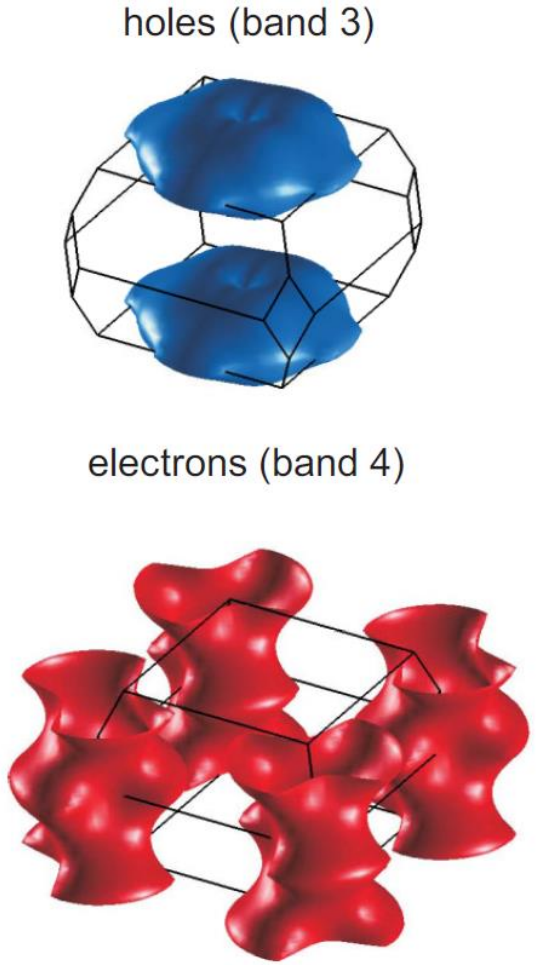


https://nationalmaglab.org/user-facilities/pulsed-field-facility/pff-measurement-techniques/torque-magnetometry-pff

Torque Magnetometry of $CaFe_2P_2$



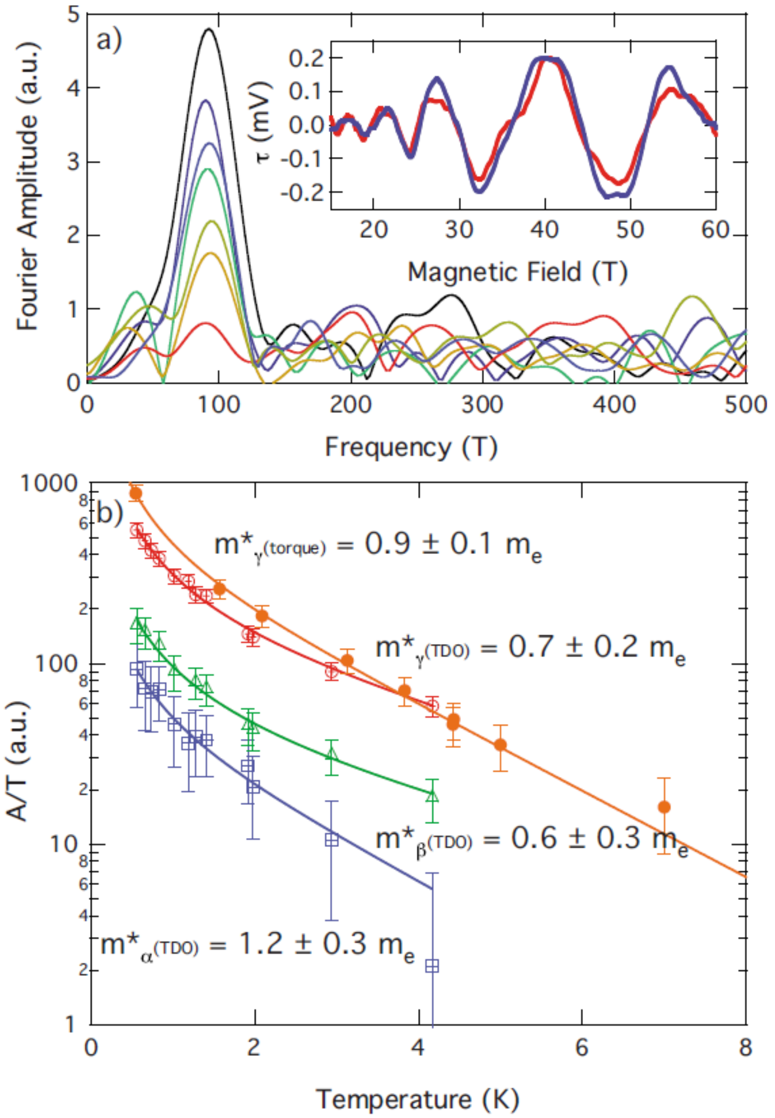


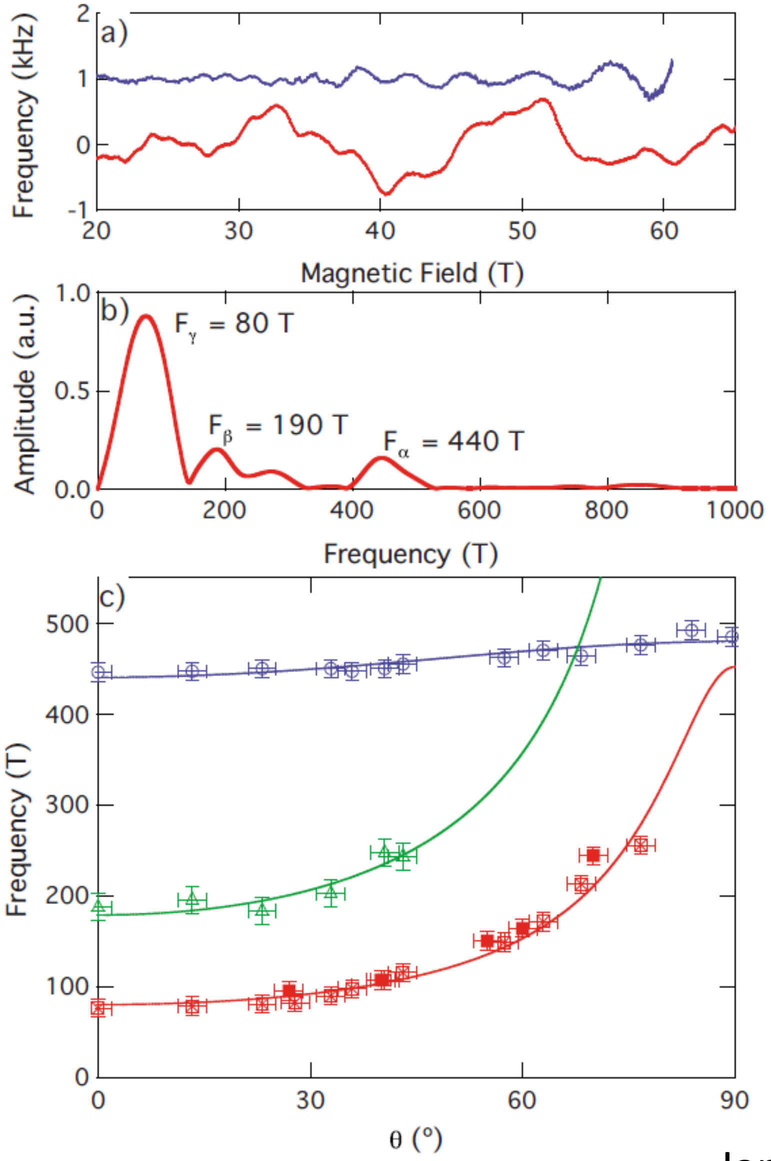


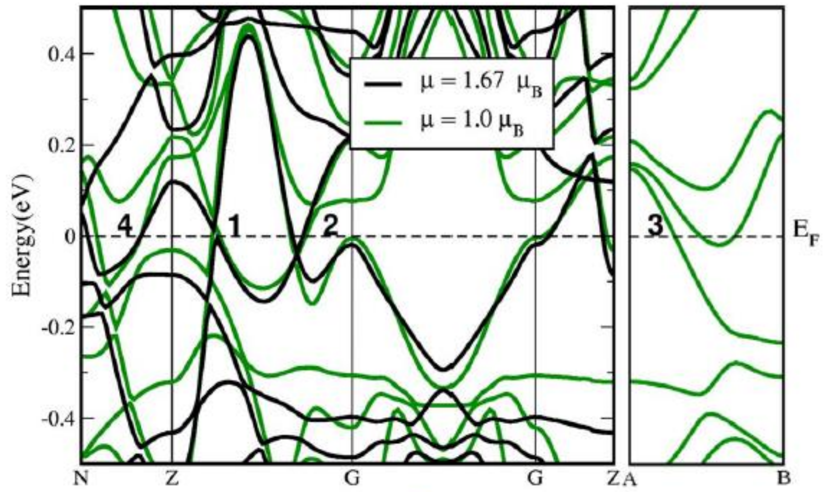
$$F = (\hbar/2\pi e)A_k$$

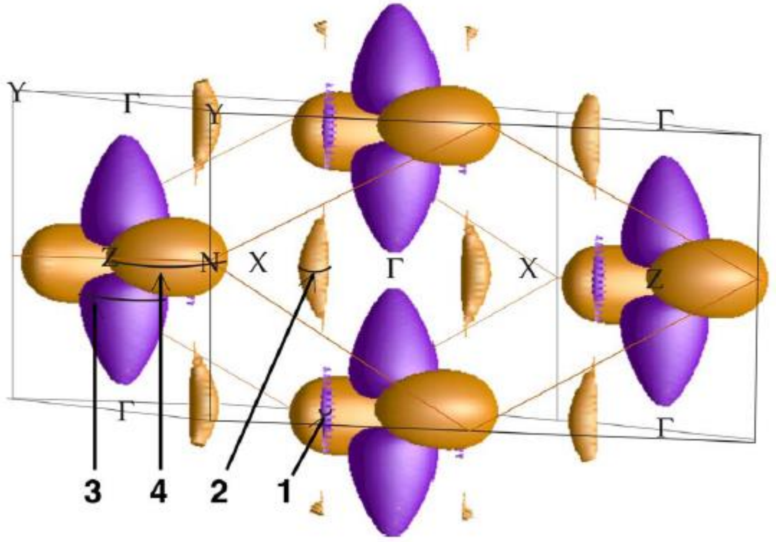
Amalia Coldea *Phys. Rev. Lett.* **103**, 026404 (2009)

Torque Magnetometry of $BaFe_2As_2$ in Pulsed Fields



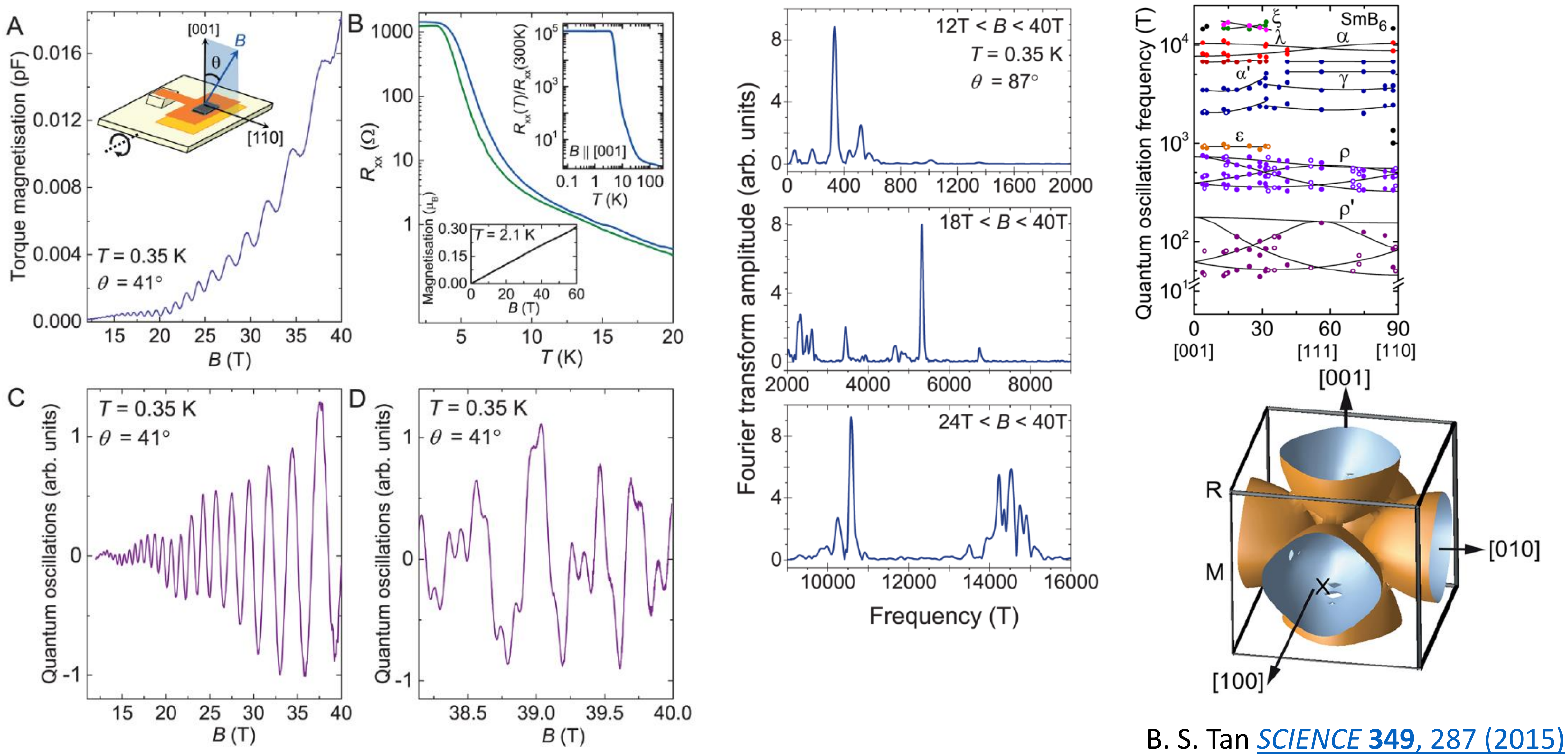






James Analytis *Phys. Rev. B* **80**, 064507 (2009)

Unconventional Fermi surface of the Kondo insulator SmB_6



B. S. Tan *SCIENCE* **349**, 287 (2015)