LETTER

https://doi.org/10.1038/s41586-018-0274-0

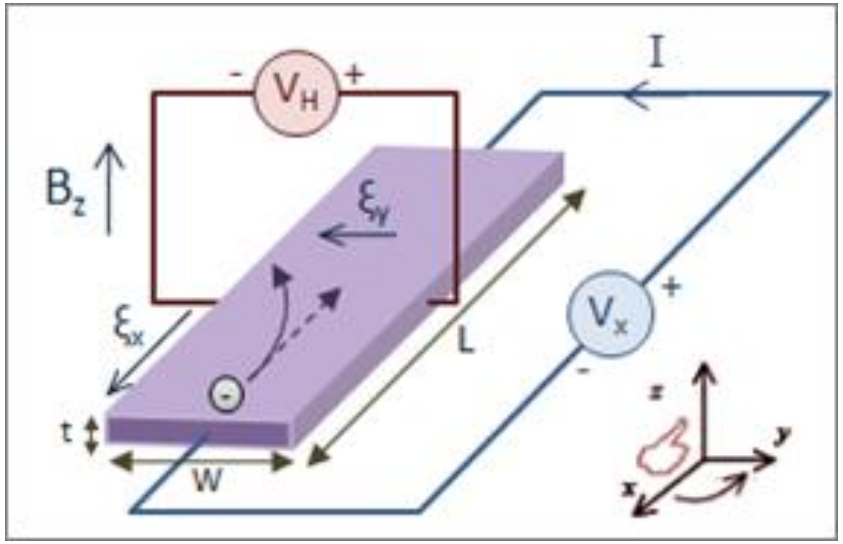
Majorana quantization and half-integer thermal quantum Hall effect in a Kitaev spin liquid

Y. Kasahara[1], T. Ohnishi[1], Y. Mizukami[2], O. Tanaka[2], Sixiao Ma[1], K. Sugii[3], N. Kurita[4], H. Tanaka[4], J. Nasu[4], Y. Motome[5], T. Shibauchi[2] & Y. Matsuda[1]*

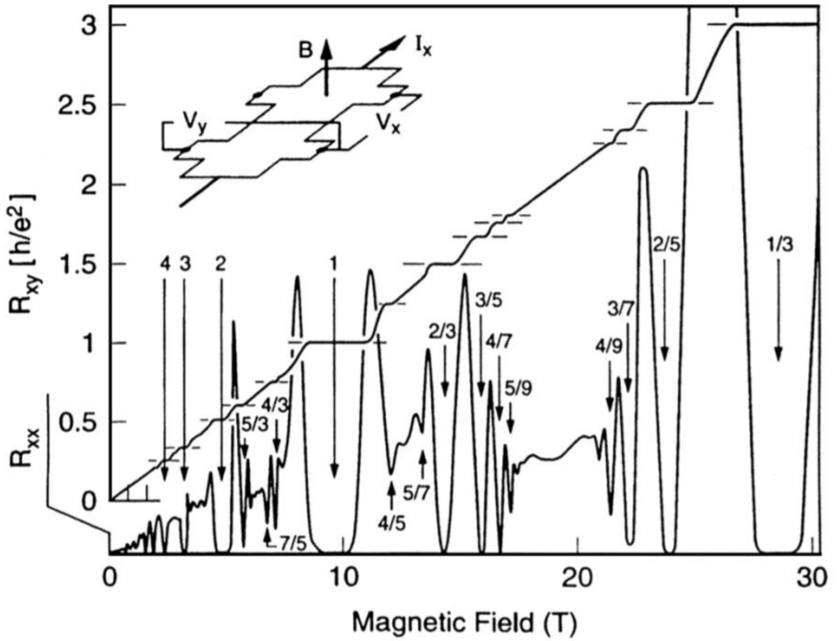
By Melissa Will (melissa.will@tum.de)

Proseminar 27.04.2021

Quantum Hall Effect



[1]



[2]

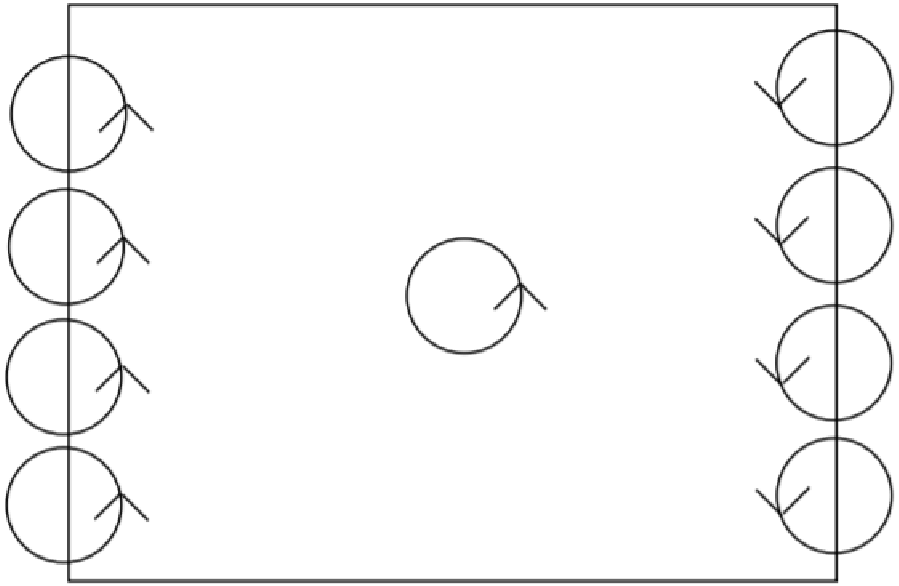
Quantization of conductivity: $\sigma_{xy}^{2D} = \nu \frac{e^2}{2\pi\hbar}$

[1] https://en.wikipedia.org/wiki/Hall_effect#/media/File:Hall_Effect_Measurement_Setup_for_Electrons.png
[2] Eisenstein, J. P., and H. L. Stormer. "The fractional quantum Hall effect." Science 248.4962 (1990): 1510-1516.

Quantiziation of Hall conductivity

Quantization of conductivity: $\sigma_{xy}^{2D} = \nu \frac{e^2}{2\pi\hbar}$

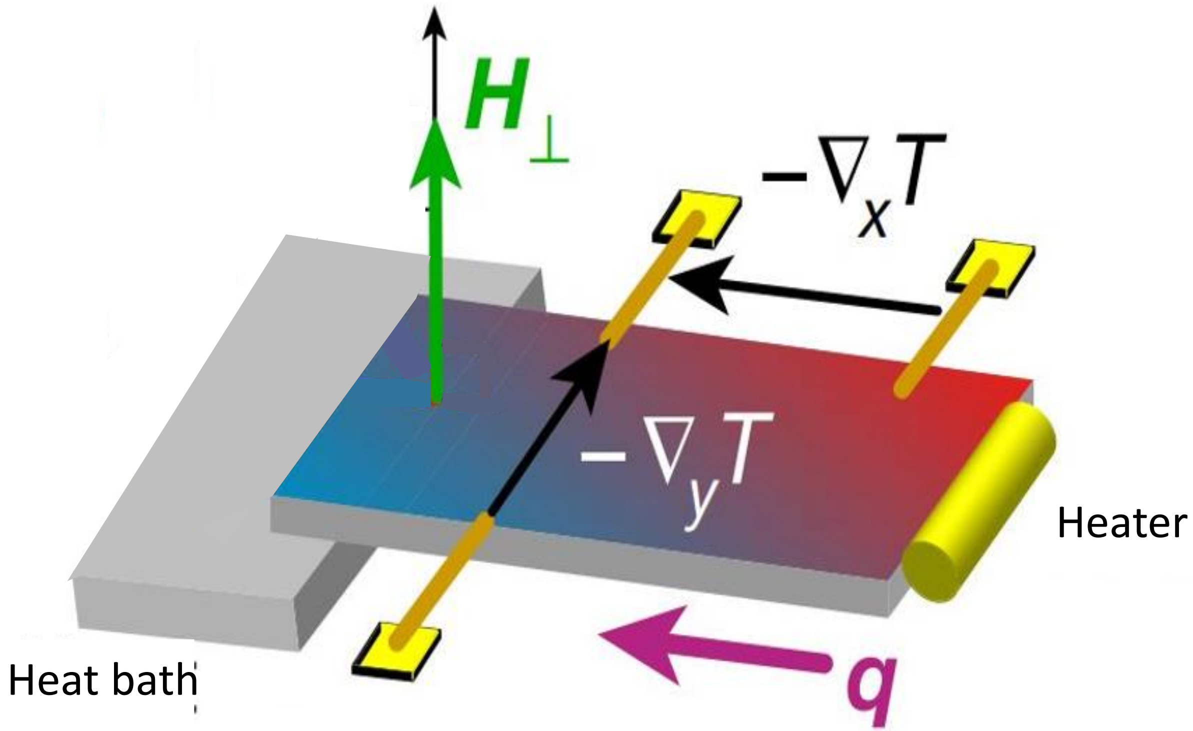
Modell of skipping orbits



[3]

[3] Tong, David. "Lectures on the quantum Hall effect." arXiv preprint arXiv:1606.06687 (2016).

Thermal Quantum Hall Effect



Starting from Quantum Hall Effect

$$\sigma_{xy}^{2D} = \nu \frac{e^2}{2\pi\hbar}$$

Using Wiedemann-Franz Law:

$$\frac{\kappa}{\sigma} = LT$$

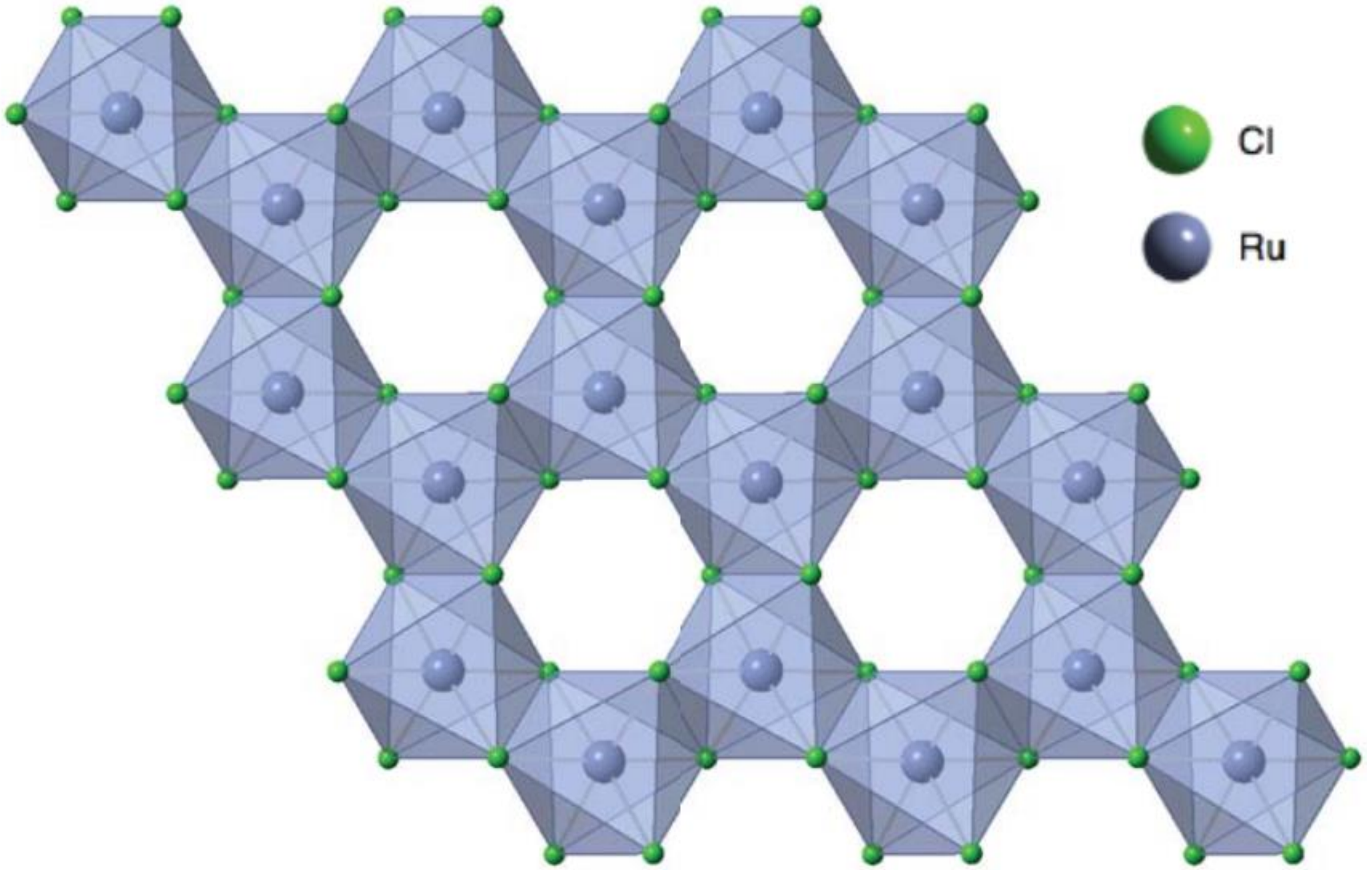
Lorenz-number:

$$L = \frac{\pi^2}{3}\left(\frac{k_B}{e}\right)^2$$

Yields

$$\frac{\kappa_{xy}^{2D}}{T} = \sigma_{xy}^{2D} L = \nu \frac{\pi}{6}\frac{k_B^2}{\hbar}$$

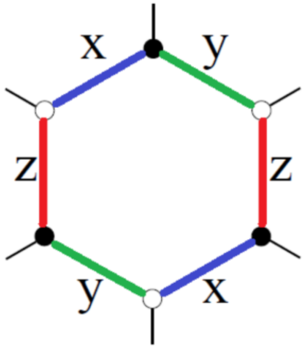
RuCl3



[4]

[4] Broholm, C., et al. "Quantum spin liquids." Science 367.6475 (2020).

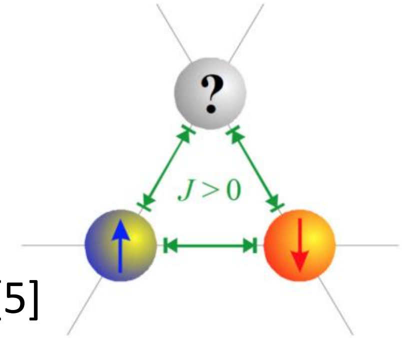
Kitaev Model



[5]

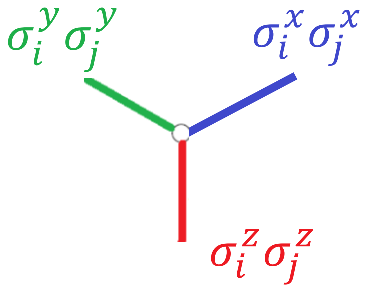
$$\hat{H} = J_x \sum_{\{<i,j>\,\epsilon x\}} \sigma_i^x \sigma_j^x + J_y \sum_{\{<i,j>\,\epsilon y\}} \sigma_i^y \sigma_j^y + J_z \sum_{\{<i,j>\,\epsilon z\}} \sigma_i^z \sigma_j^z$$

Geometric frustrated



[5]

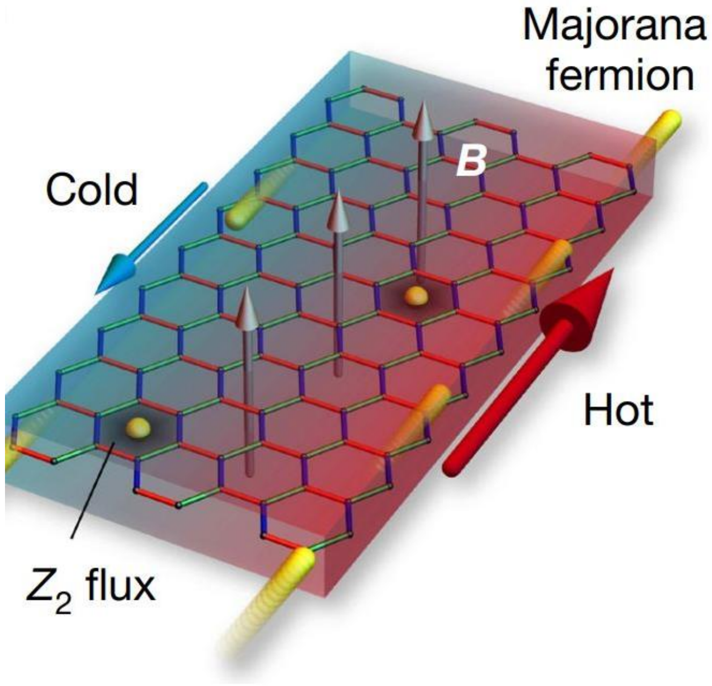
Exchange frustrated



Quantum Spin liquid
→ No ordering for all temperatures

[5] Zschocke, Fabian. Kitaev Honeycomb Model: Majorana Fermion Representation and Disorder. Diss. Saechsische Landesbibliothek-Staats-und Universitaetsbibliothek Dresden, 2016.

Expectation – Kitaev Model and Thermal Hall effect



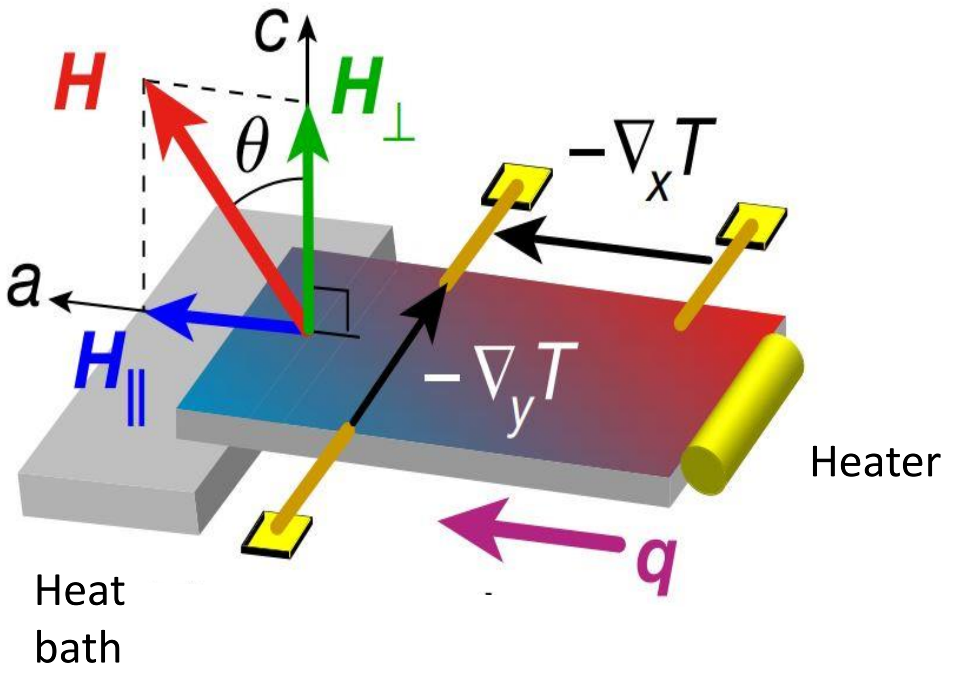
Majorana fermions

- Are their own antiparticles
  → No charge

- Expected thermal conductivity:

$$\frac{\kappa_{xy}^{2D}}{2}$$

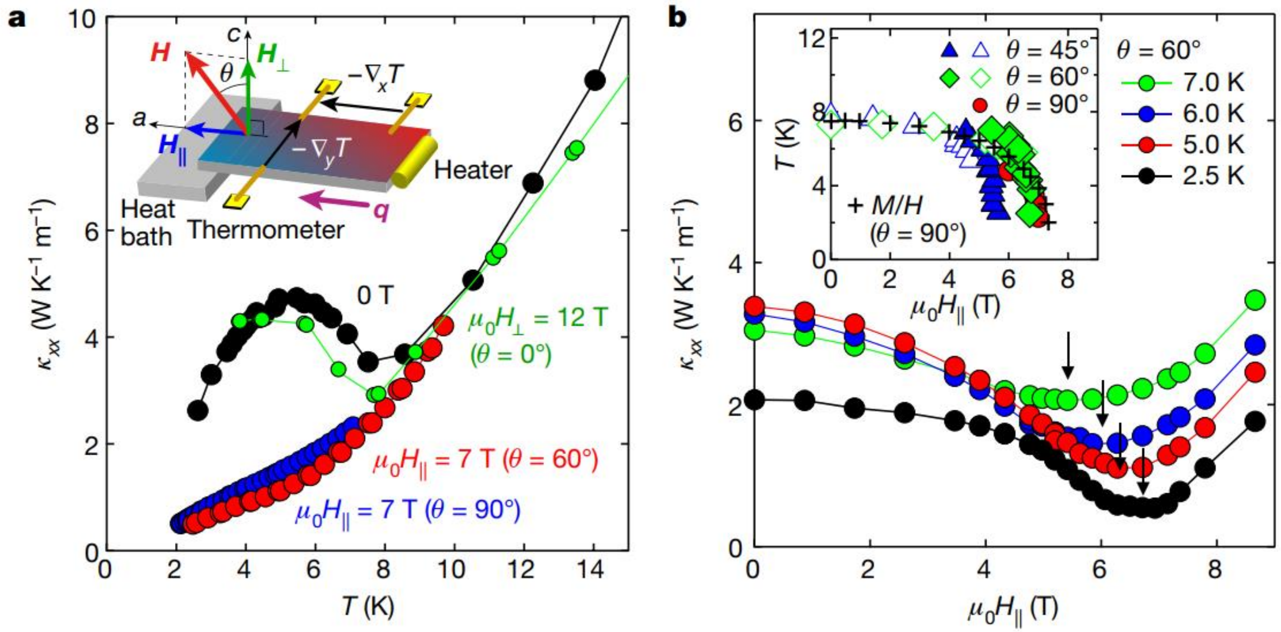
Experimental Setup



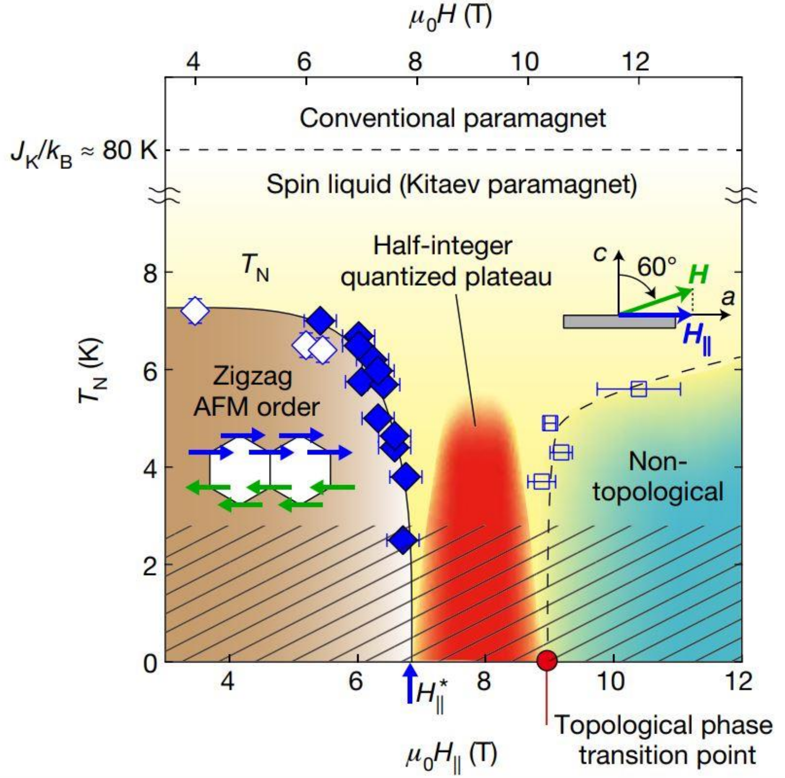
1. Phase diagram

Result - Longitudinal thermal conductivity in α-RuCl3

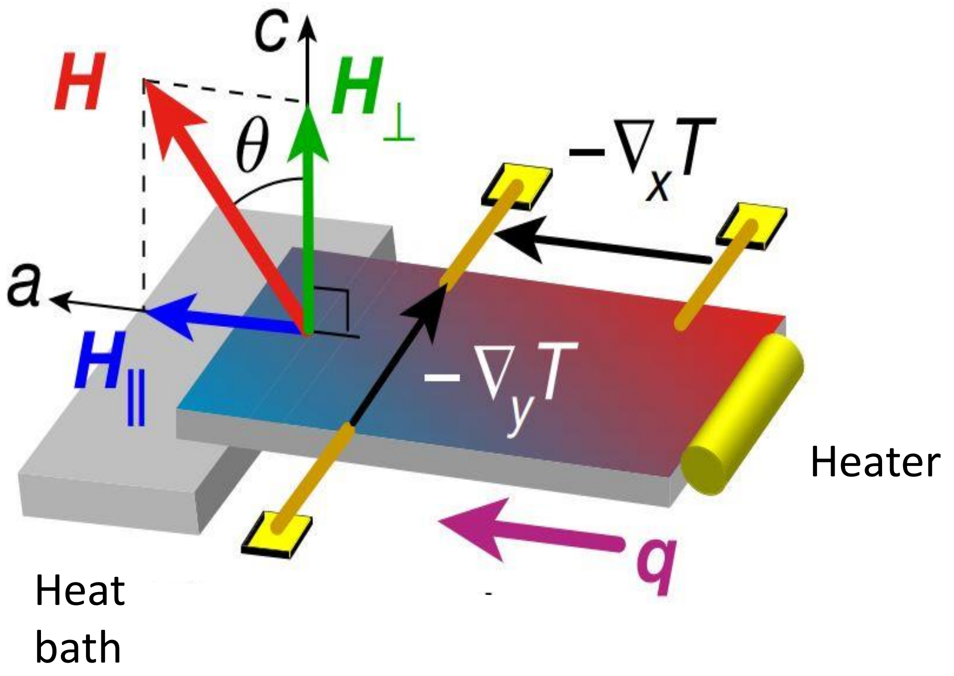
Θ *variable* $\qquad\qquad$ $\Theta = 60^{\circ}$



Phase diagram for $\Theta = 60^{\circ}$



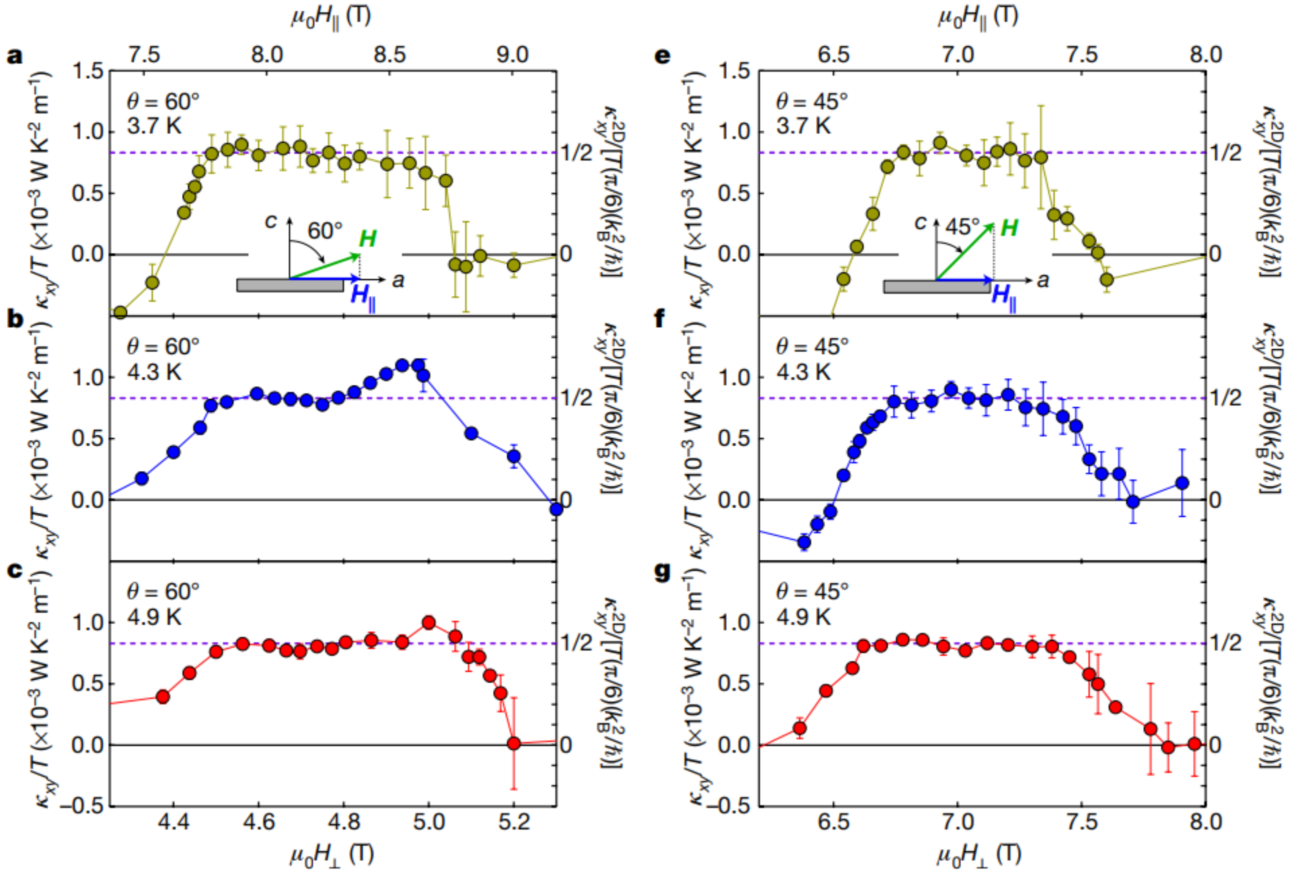
Experimental Setup



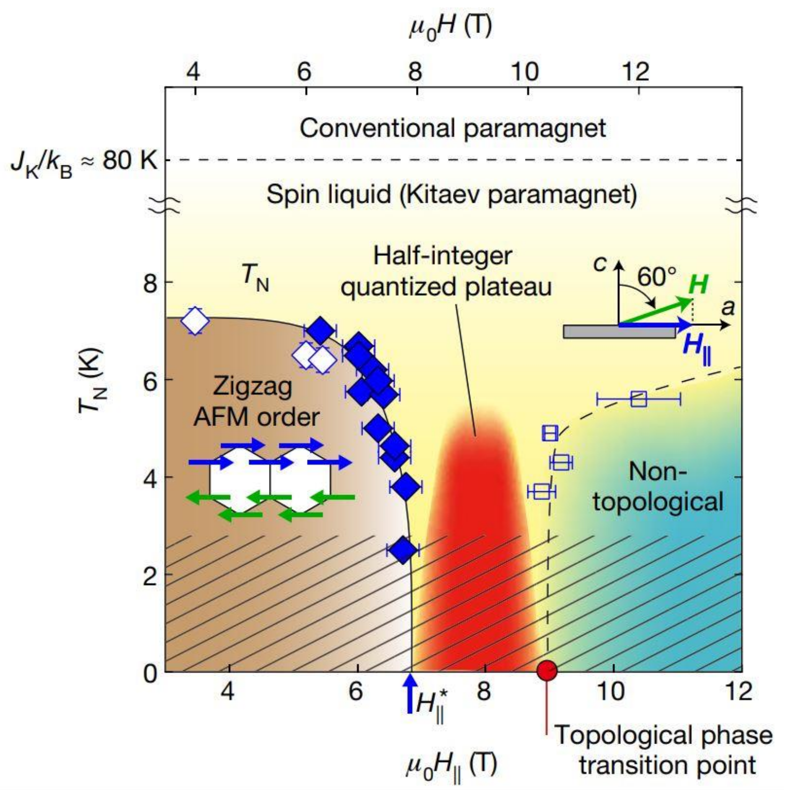
2. Measurement of thermal conductance

Result – Half-integer thermal Hall conductance plateau

$\Theta = 60^{\circ}$ $\Theta = 45^{\circ}$

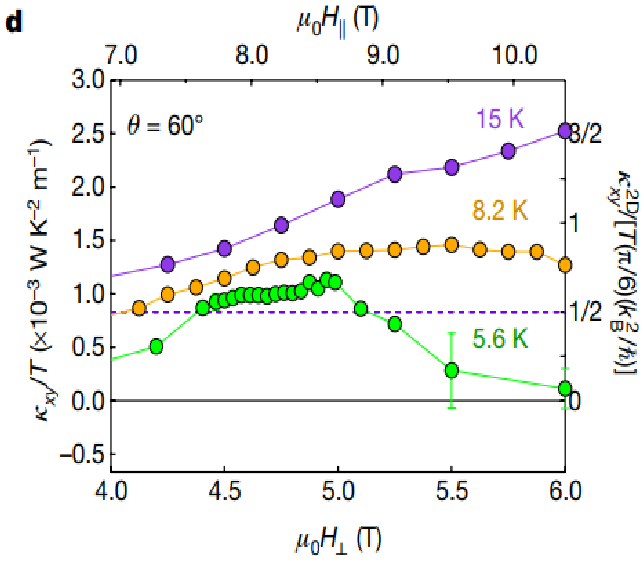


Phase diagram for $\Theta = 60^{\circ}$

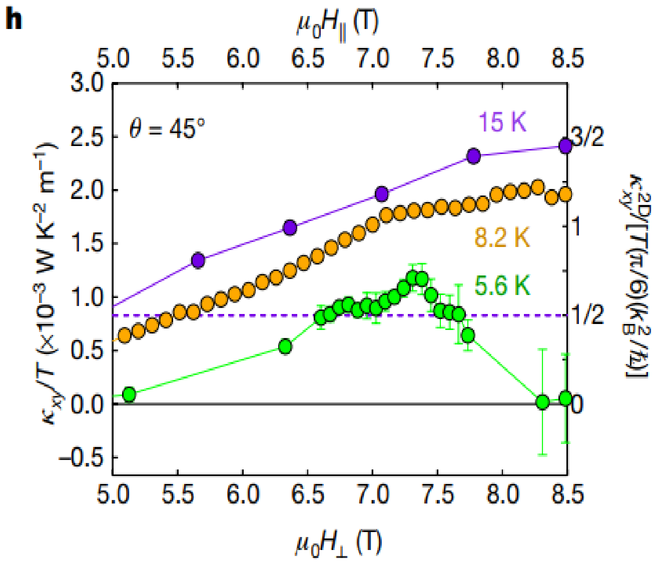


Result – Temperature dependence of the thermal Hall conductance

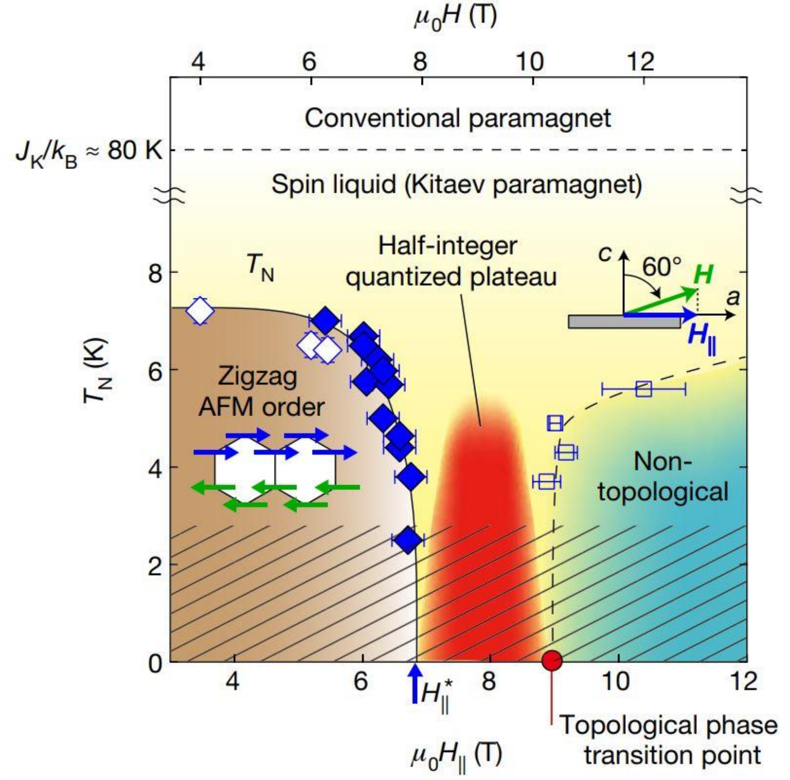
$\Theta = 60^{\circ}$



$\Theta = 45^{\circ}$



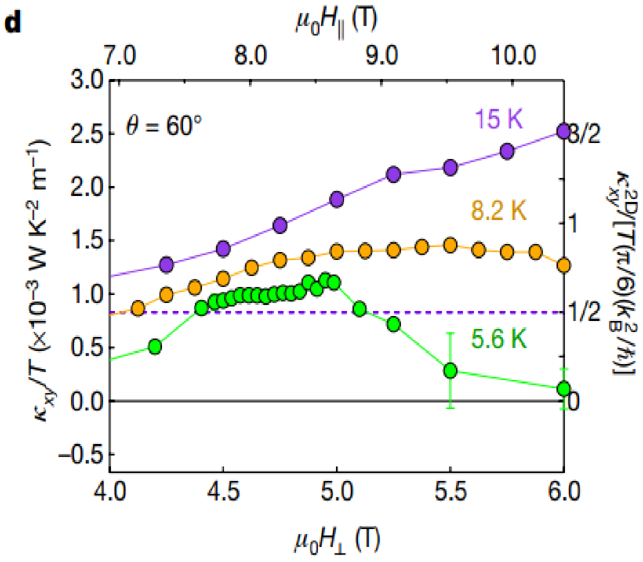
Phase diagram for $\Theta = 60^{\circ}$

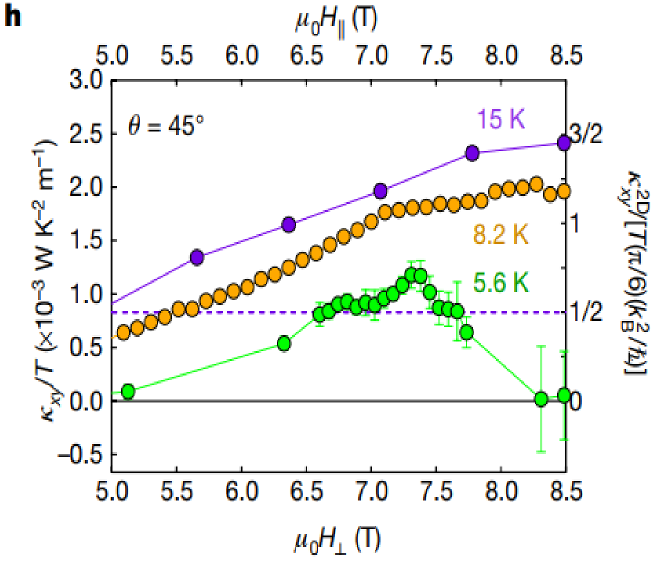


Result – Temperature dependence of the thermal Hall conductance

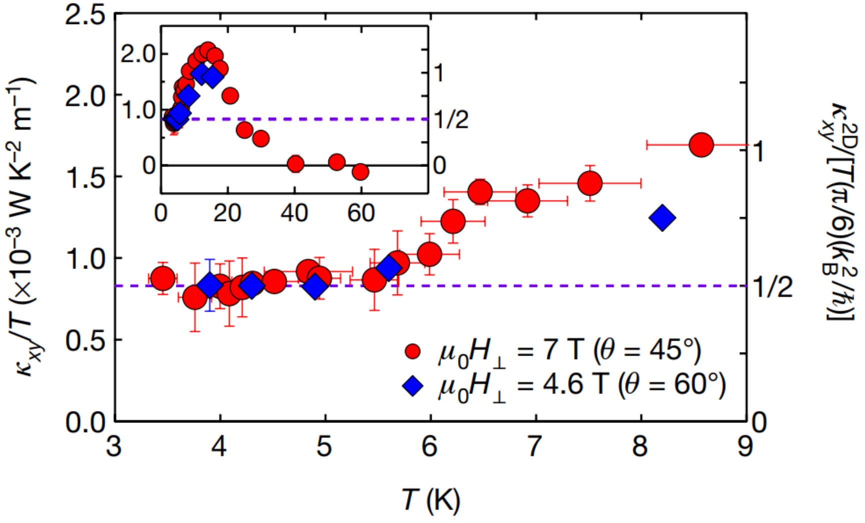
$\Theta = 60^\circ$

$\Theta = 45^\circ$





Summary



Summary

- Measurement of half integer quantum Hall conductance plateau

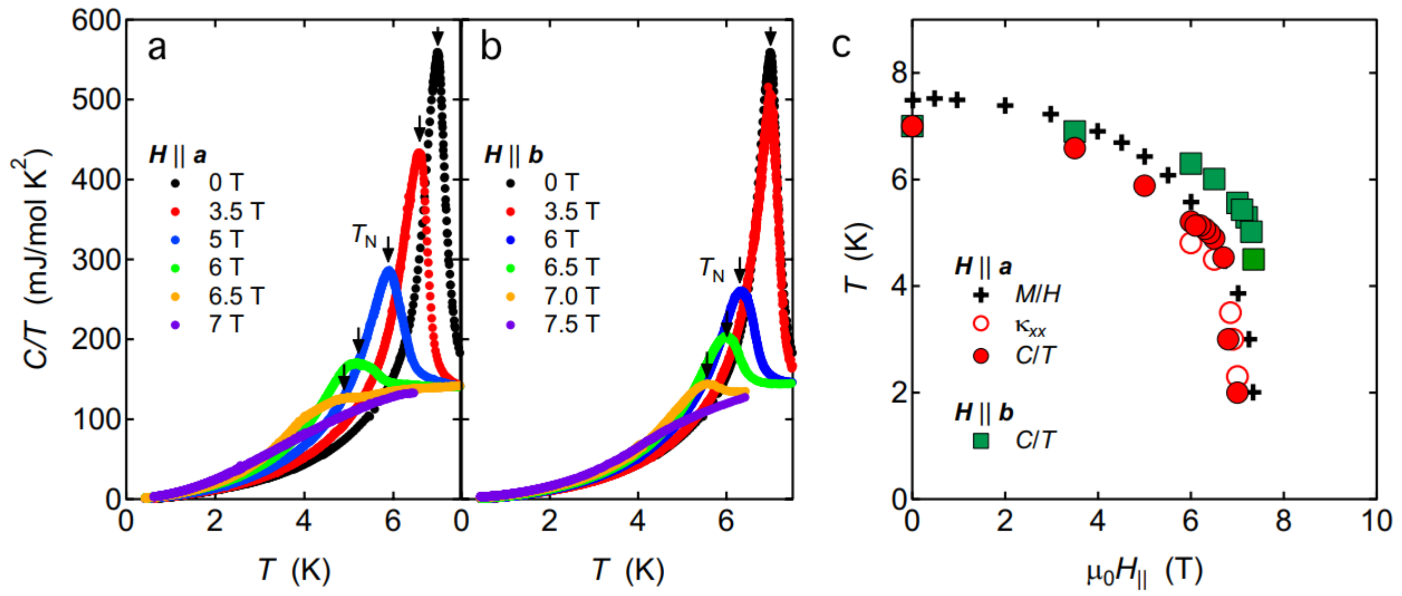
  → Direct consequence of the chiral Majorana edge current

- near vanishing of $\frac{\kappa_{xy}^{2D}}{T}$ after its rapid suppression in the high-field regime demonstrates the disappearance of chiral Majorana edge currents

  → suggests a topological quantum phase transition from the non-trivial QSL to a trivial high-field state

- high-field effects or non-Kitaev interactions deserve further study

Result – Heat capacity



Phase diagram for $\Theta = 60^\circ$