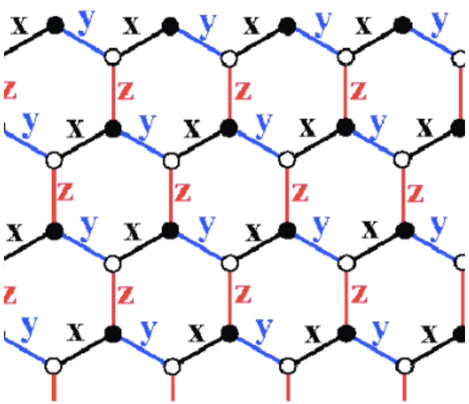
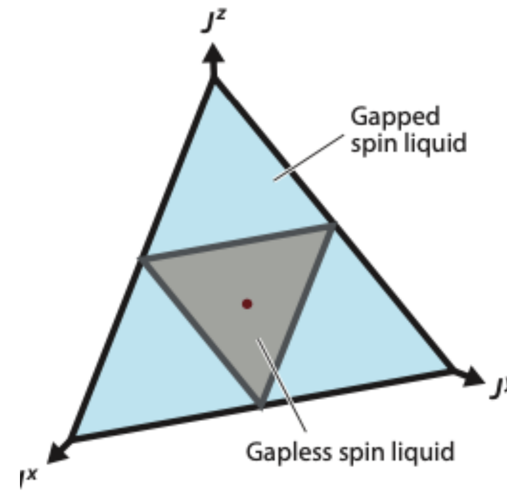
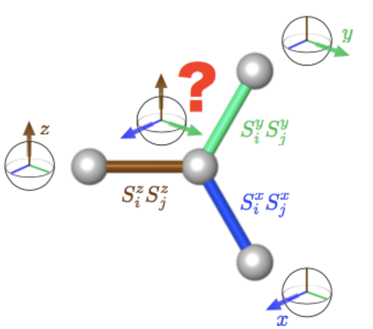
Kitaev Spin Liquids



Context ✓
The Model ✓

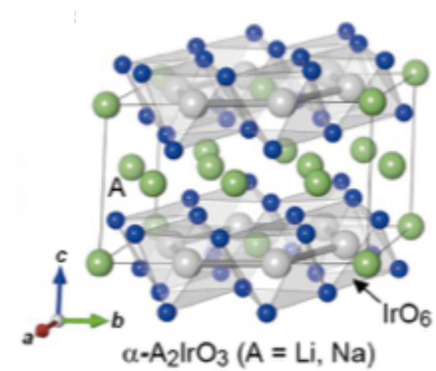


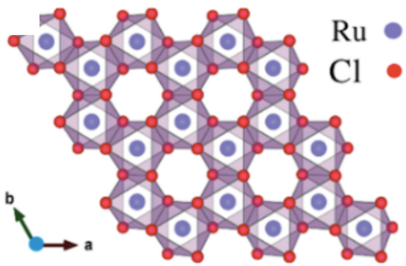
Skanda "Twisted Bilayer Graphene"



Experimental Realizations

Detection of
Majorana Fermions ??



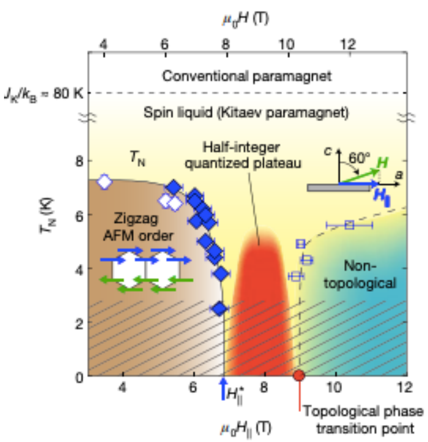


Experimental Detection of Majorana Fermions ??

Kitaev Materials

Laboratory Sighting of Majorana Fermions ??

Focus: Thermal Hall Measurements on $\alpha - RuCl_3$

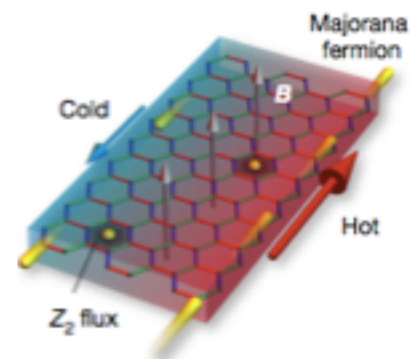


Background

Results

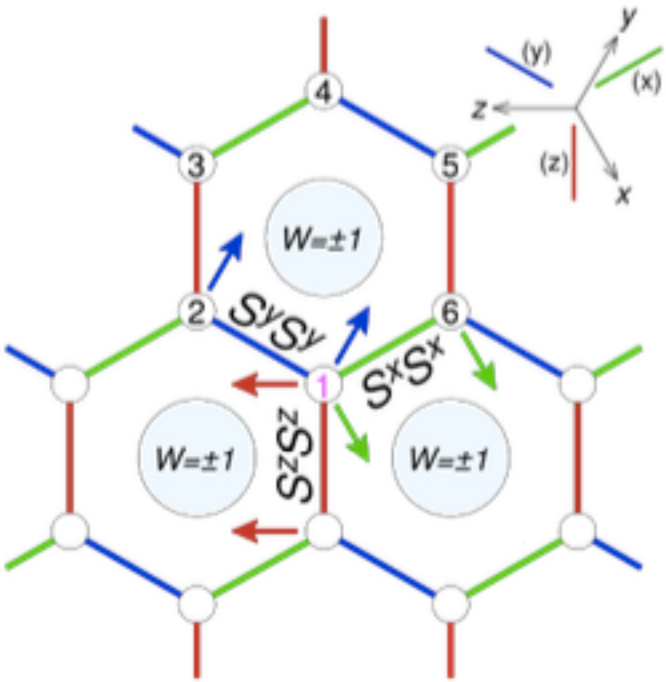
Interpretation

Subsequent Work



What ??s Would We Ask as Referees ??

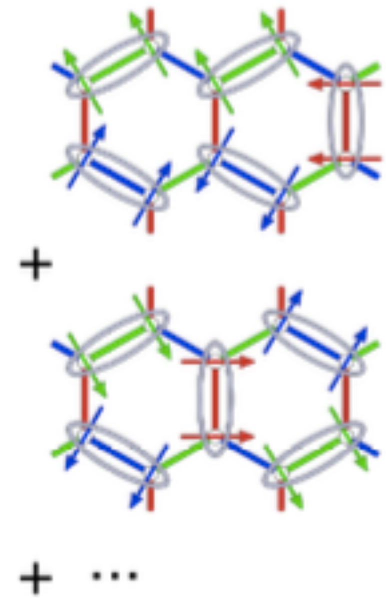
The Kitaev Model on the Honeycomb Lattice



$$H = -\sum_{<ij>_\gamma} K_\gamma S_i^\gamma S_j^\gamma$$

Ising Spins with Bond Anisotropies

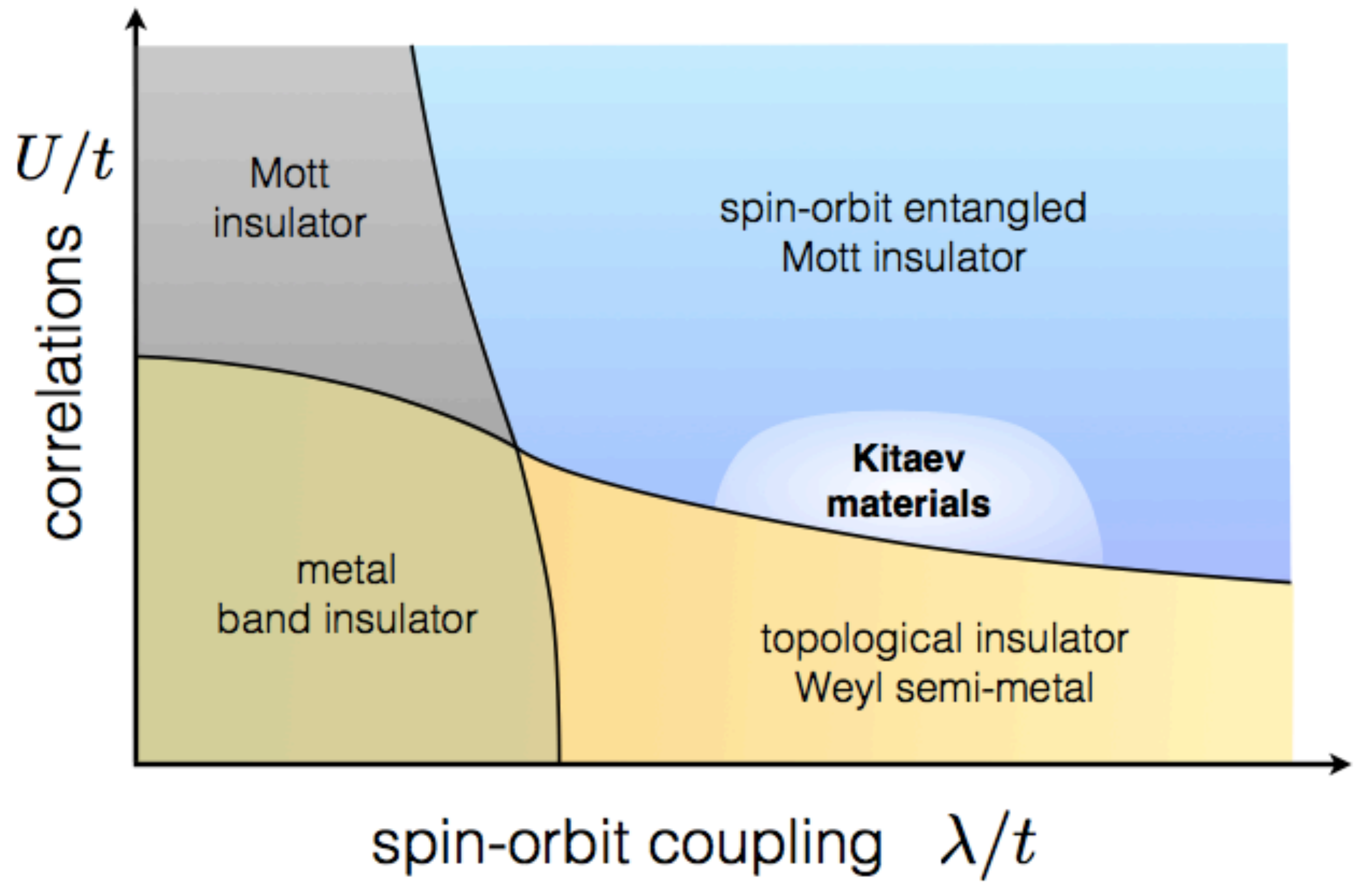
Quantum Model



Superposition of Classical Configurations (similar to RVB)

Highly Entangled Quantum Spin Liquid State

Kitaev Materials



S. Trebst, arXiv 1701.0705

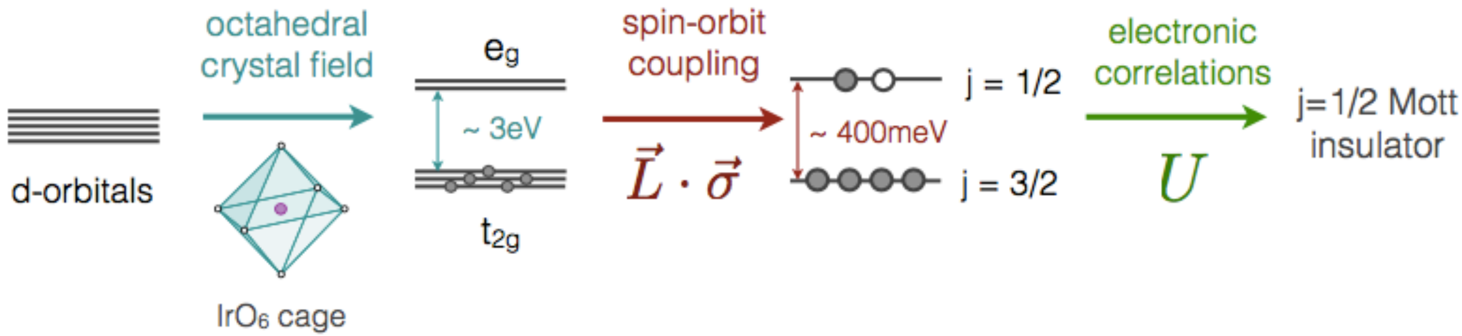


Fig. 2: *Formation of spin-orbit entangled $j = 1/2$ moments for ions in a d^5 electronic configuration such as for the typical iridium valence Ir^{4+} or the ruthenium valence Ru^{3+}.*

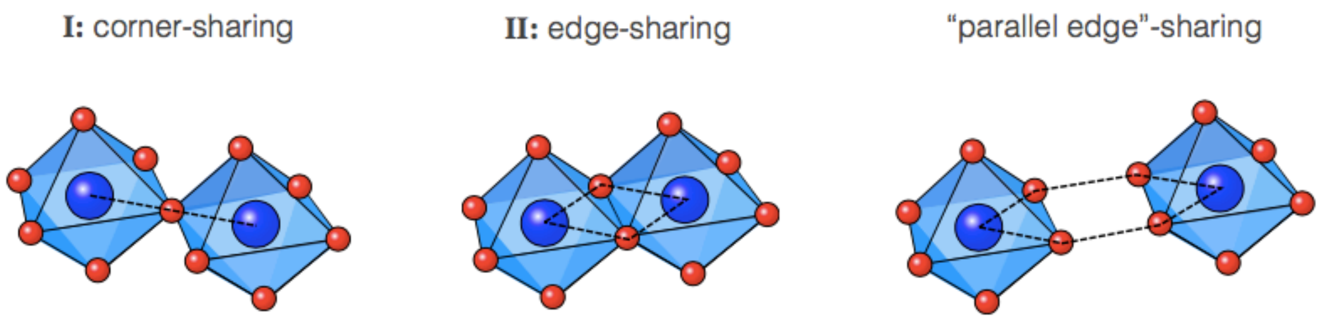


Fig. 3: *Illustration of possible geometric orientations of neighboring IrO_6 octahedra that give rise to different types of (dominant) exchange interactions between the magnetic moments located on the iridium ion at the center of these octahedra. For the corner-sharing geometry (I) one finds a dominant symmetric Heisenberg exchange, while for the edge-sharing geometries (II) one finds a dominant bond-directional, Kitaev-type exchange.*

Ab Initio Calculations

$$H = -\sum_{\gamma-\text{bonds}} J\,\mathbf{S}_i\mathbf{S}_j + K\,S_i^\gamma S_j^\gamma + \Gamma\left(S_i^\alpha S_j^\beta + S_i^\beta S_j^\alpha\right)$$

$$J = \cos\phi,\;\; K = \sin\phi$$

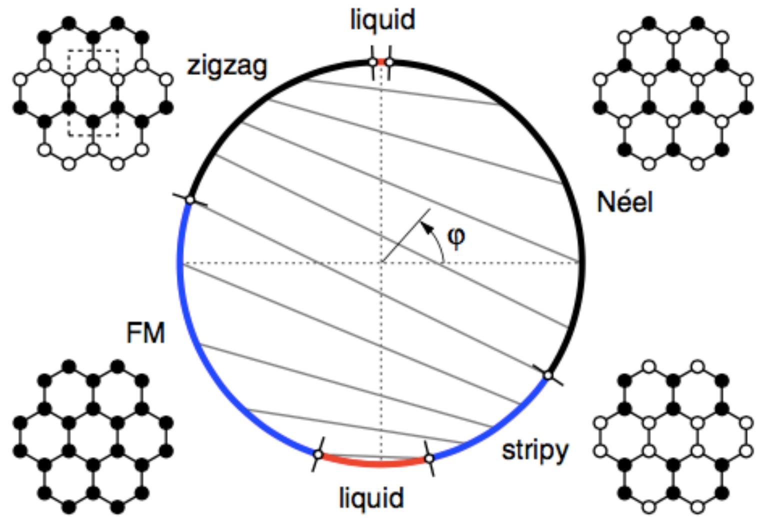


Fig. 6: *Phase diagram of the Heisenberg-Kitaev model, reproduced from Ref. [63].*

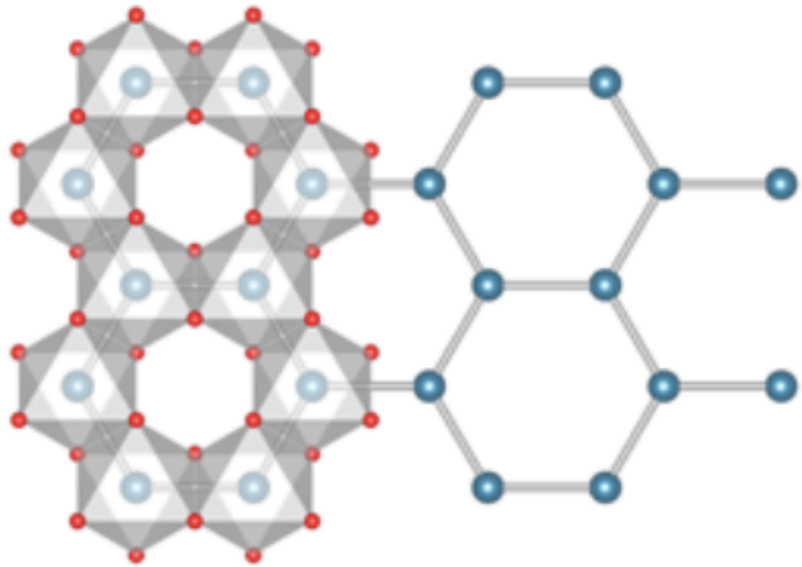


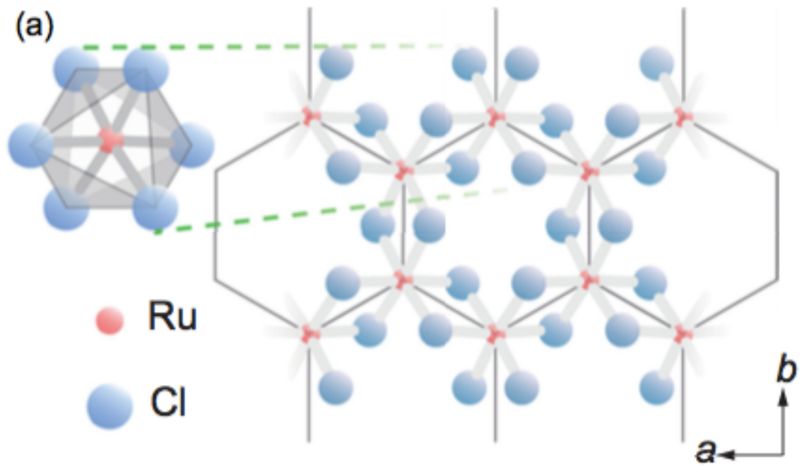
Fig. 7: *Crystal structure of the honeycomb Kitaev materials A_2IrO_3 such as Na_2IrO_3 and α-Li_2IrO_3.*

Zig-Zag Magnetic Ordering at T = 15 K

Trigonal Distortions

Next-Nearest Neighbor Exchange …….

α-$RuCl_3$



Edge-Sharing Octahedra

Negligible trigonal distortion

SOC smaller than in 5d irritates (but argued that ratio of SOC to Bandwidth comparable)

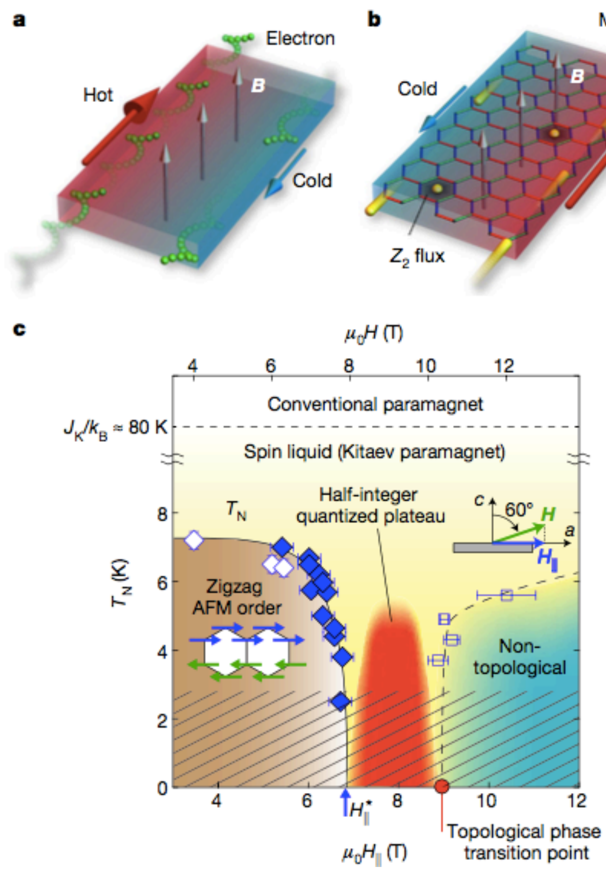
Zig-zag magnetic ordering at T = 7K

Unusual features above Neel temperature

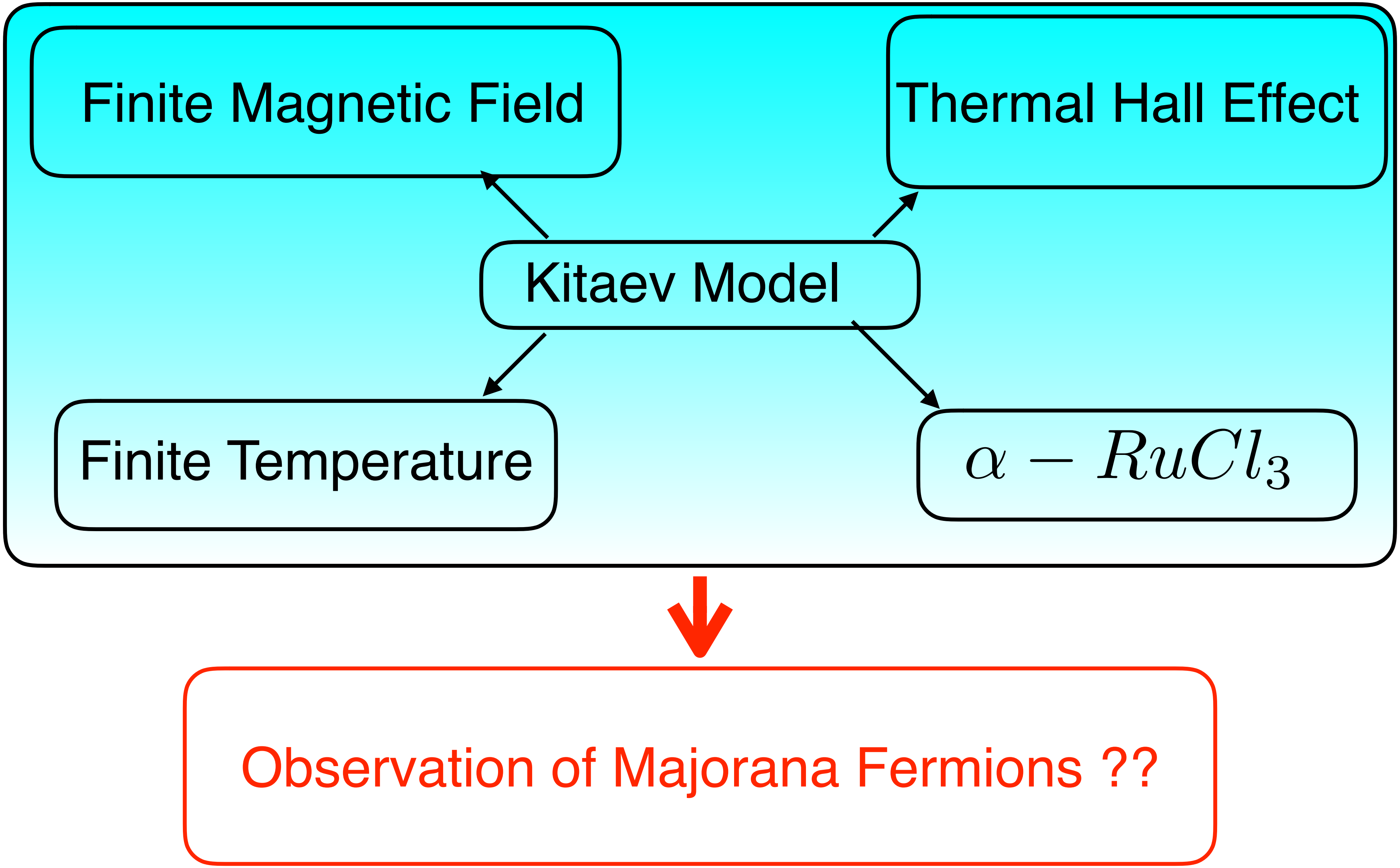
Raman, inelastic neutrons

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]*

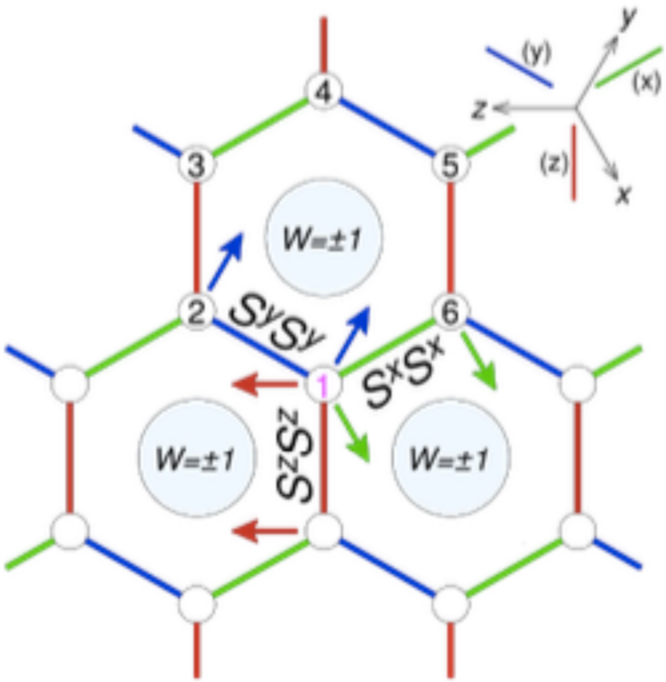


Background



Finite Magnetic Field
Thermal Hall Effect
Kitaev Model
Finite Temperature
$\alpha - RuCl_3$
Observation of Majorana Fermions ??

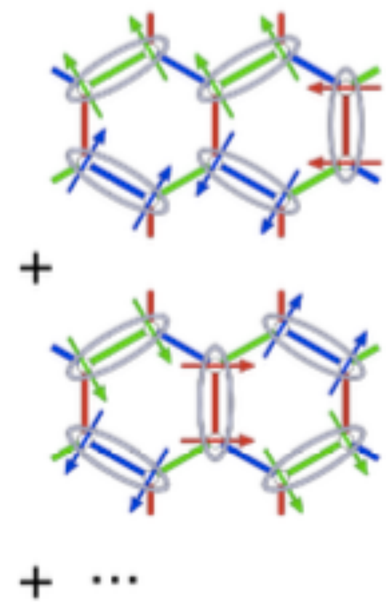
The Kitaev Model on the Honeycomb Lattice



$$H = - \sum_{<ij>_\gamma} K_\gamma S_i^\gamma S_j^\gamma$$

Ising Spins with Bond Anisotropies

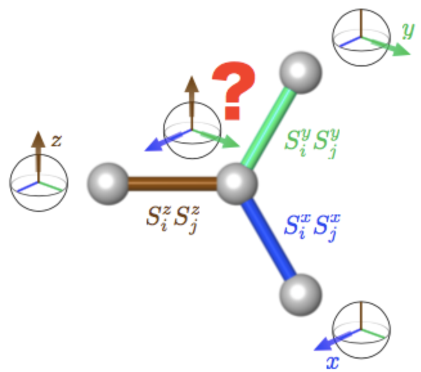
Quantum Model

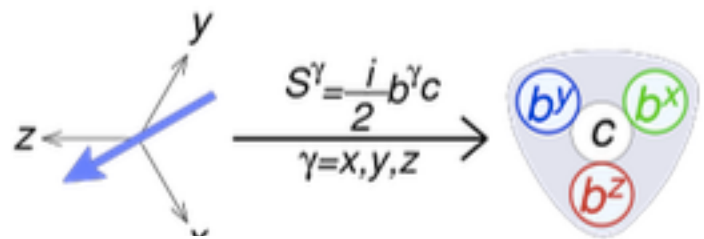


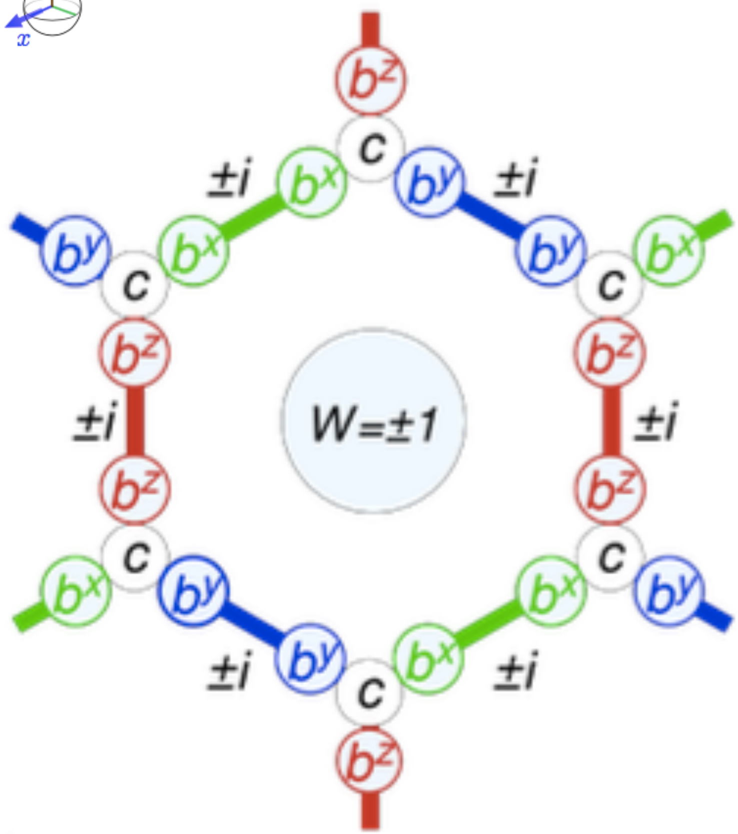
Superposition of Classical Configurations (similar to RVB)

Highly Entangled Quantum Spin Liquid State

The Kitaev Model on the Honeycomb Lattice







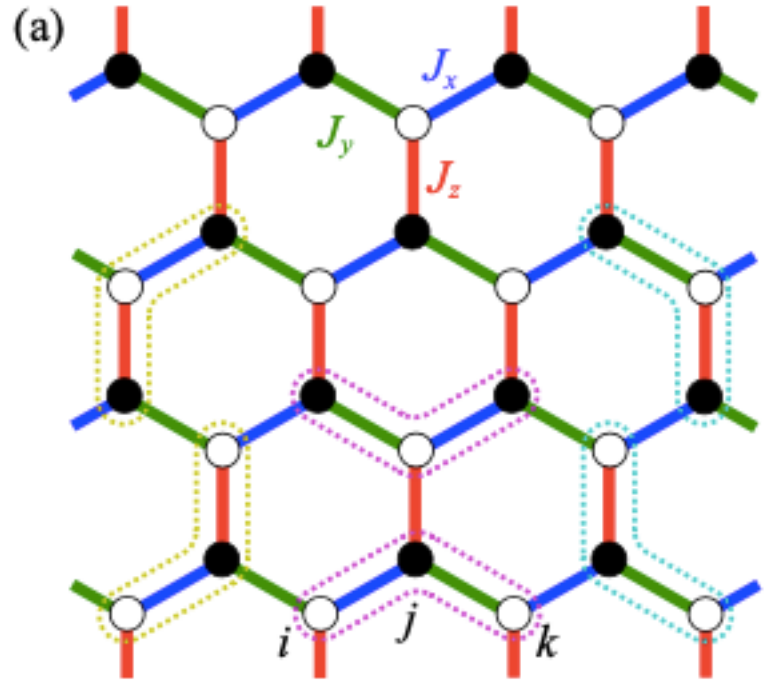
Effect of a Magnetic Field

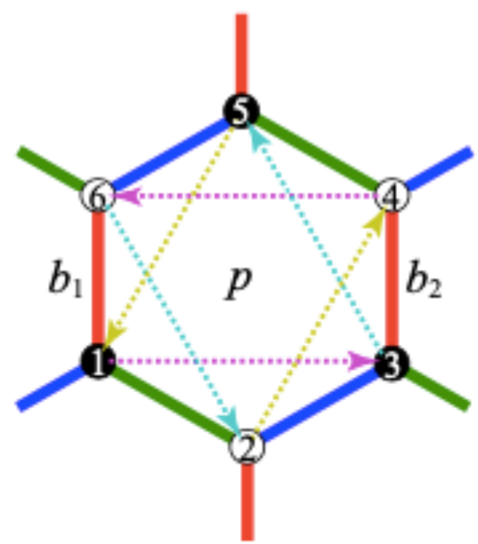
Flux Operators
no Longer Conserved
in General

Perturbative Treatment
Introduces Three-Spin
Terms

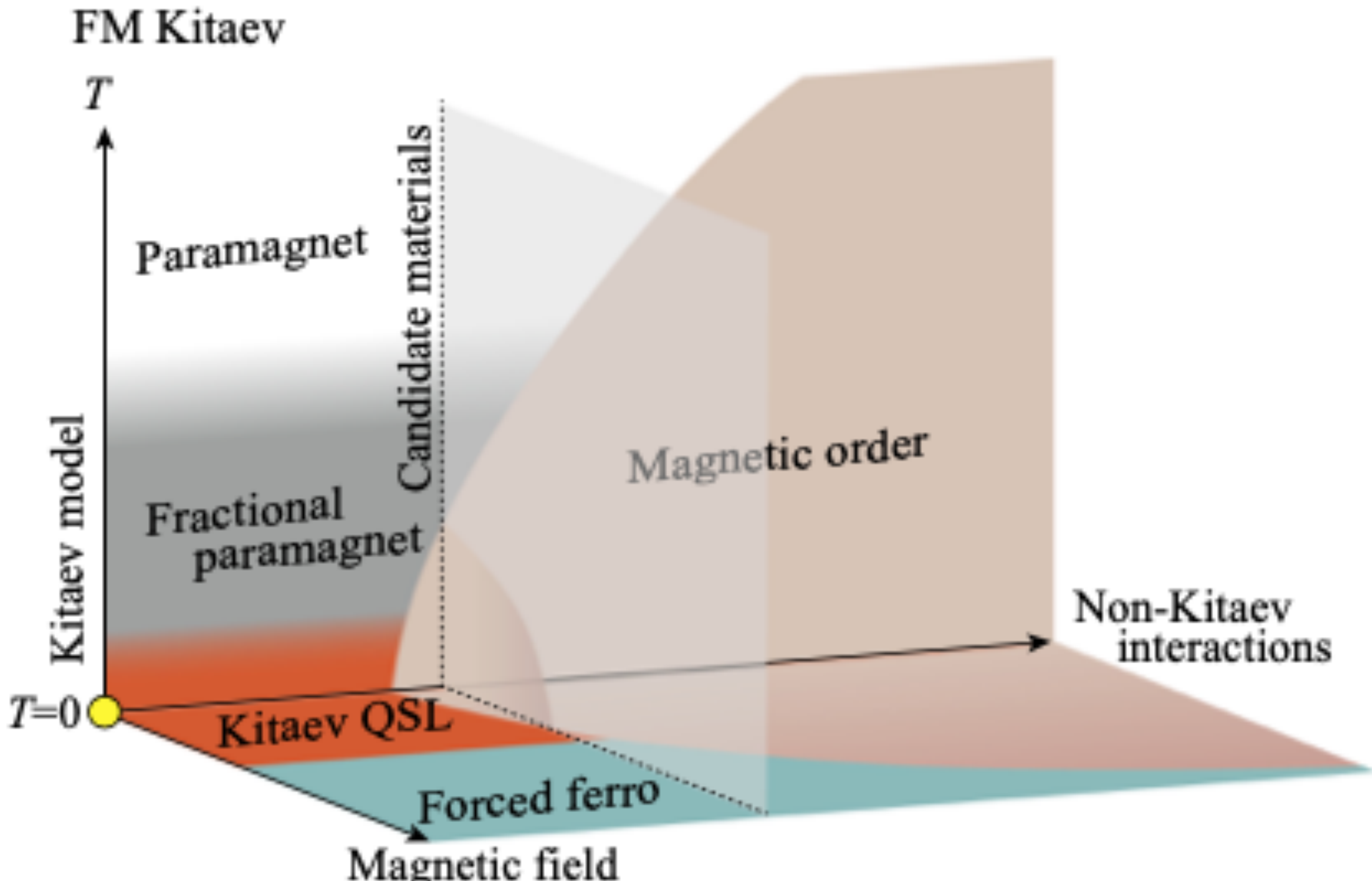
↓

Flux Operators
Remain Conserved

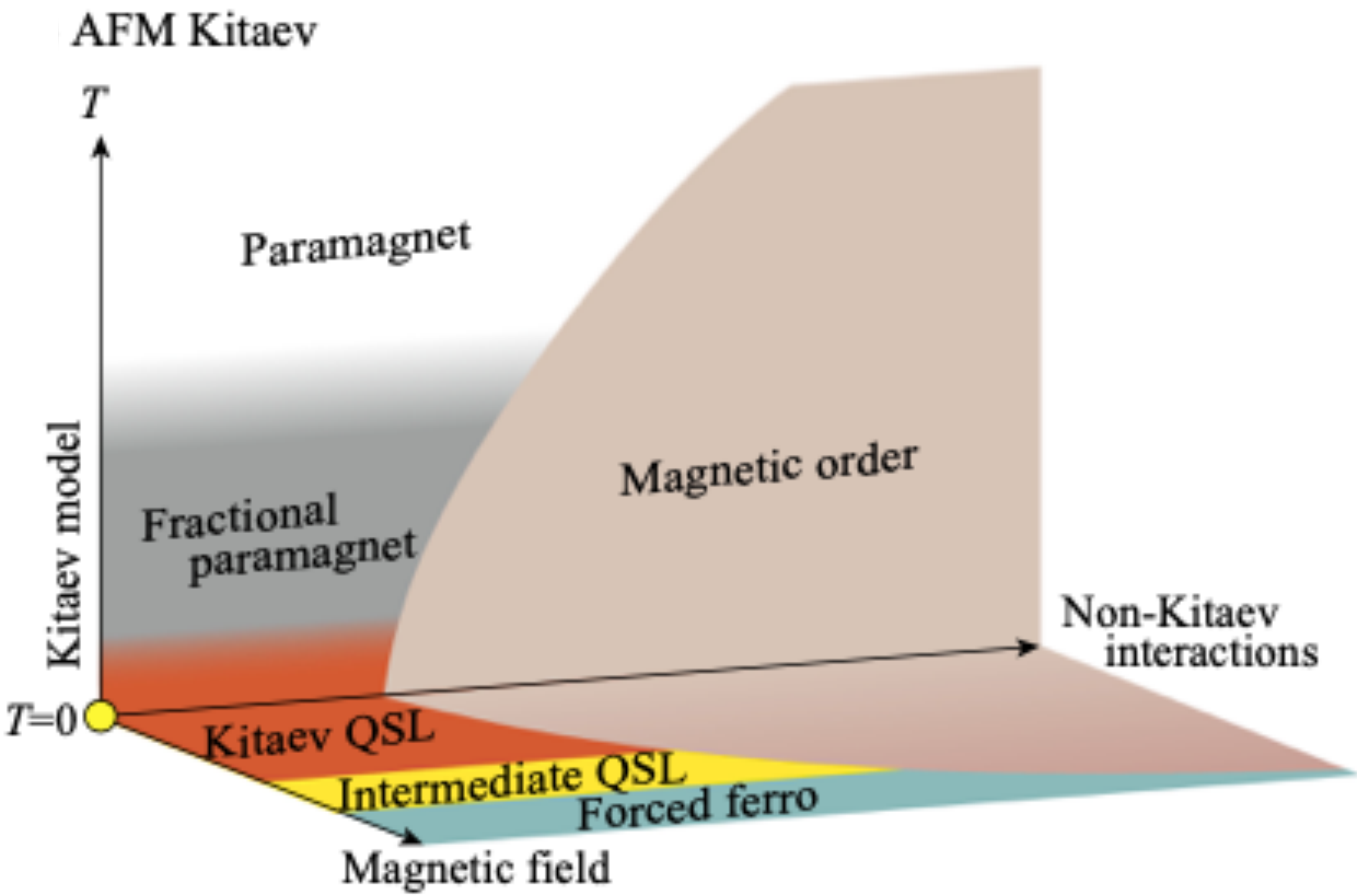




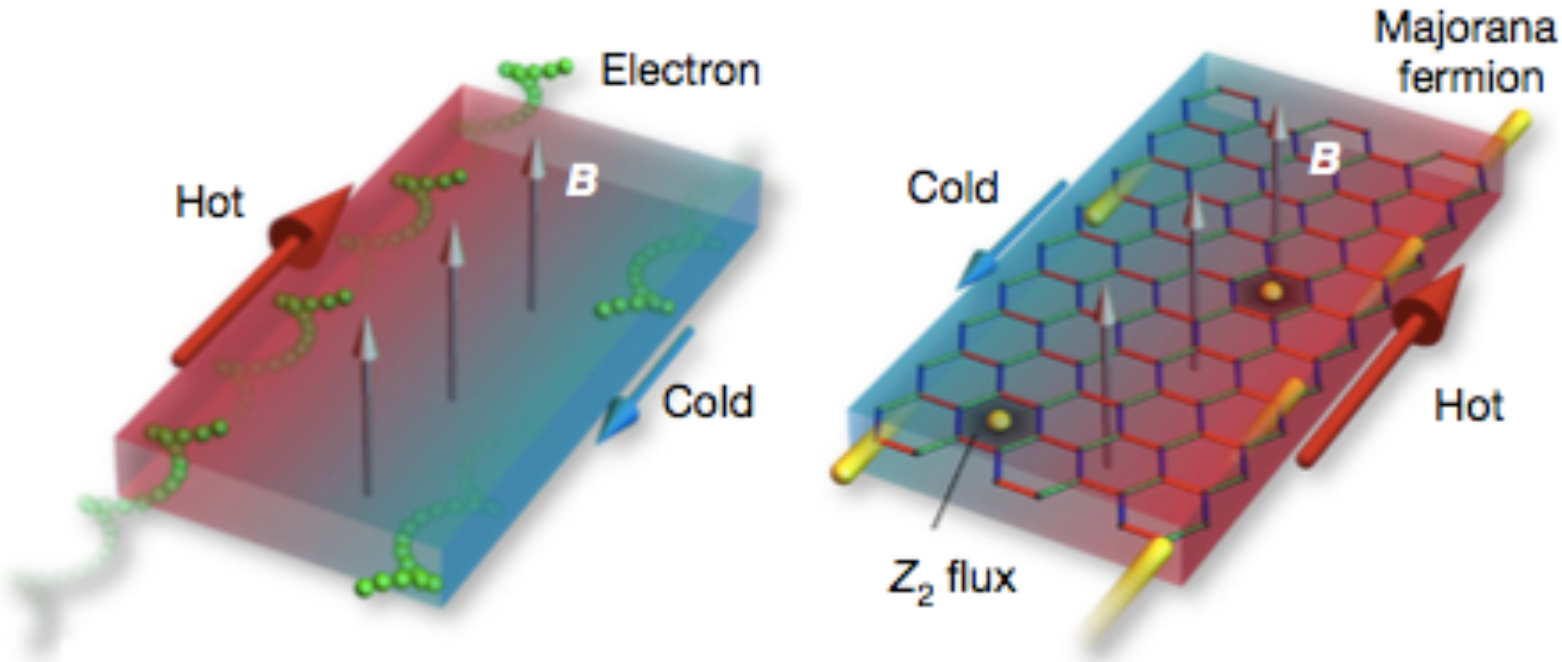
Schematic Phase Diagram



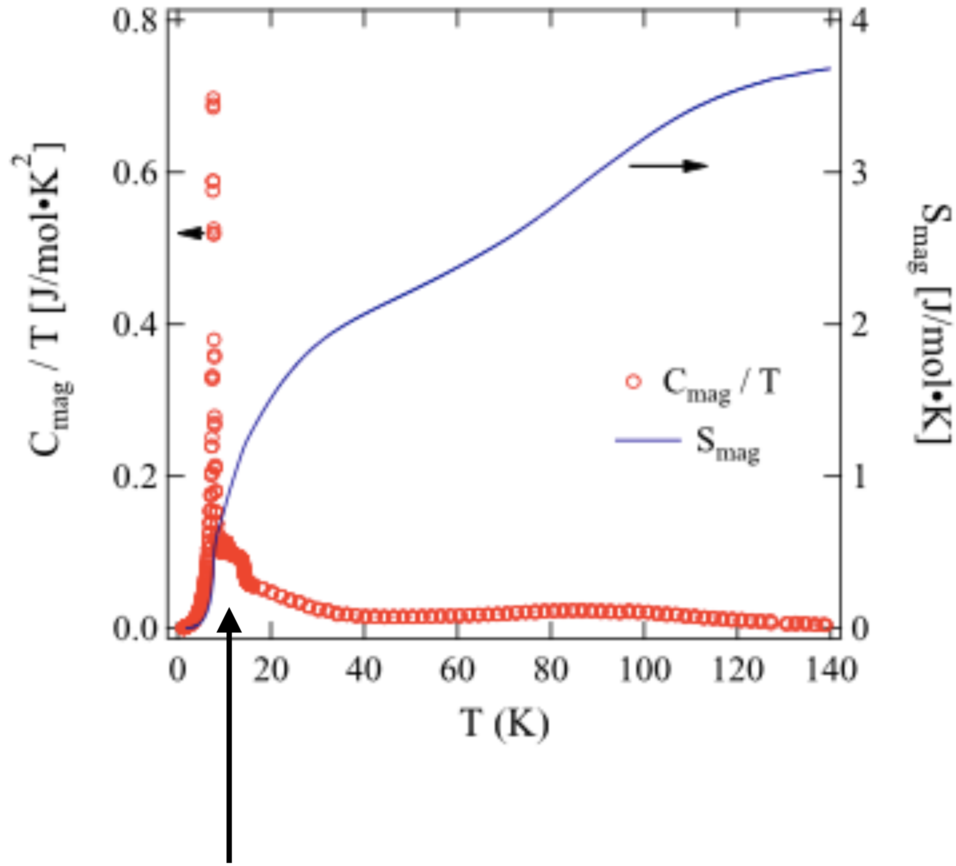
Schematic Phase Diagram



Thermal Hall Measurement



A Bit More About the Material ($\alpha - RuCl_3$)

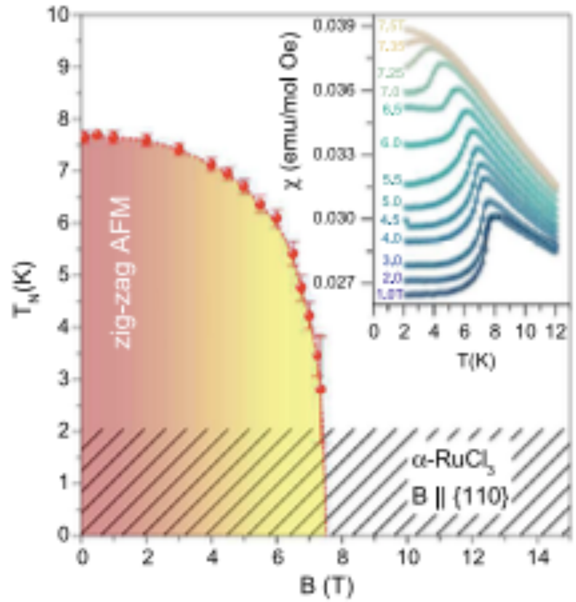


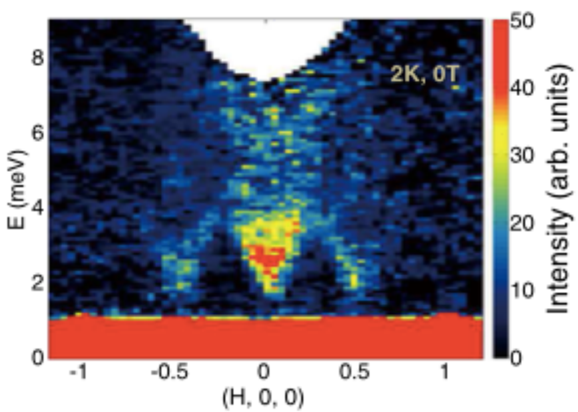
Zigzag Ordering

Suppress with Magnetic Field !!

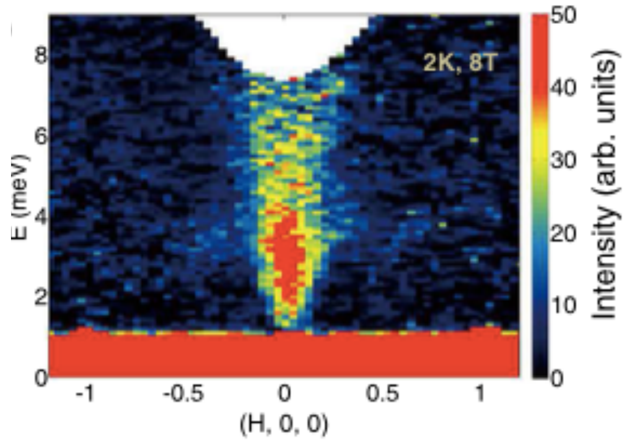
(First-Order Transition with Pressure)

Inelastic Neutron Scattering as a Function of Magnetic Field

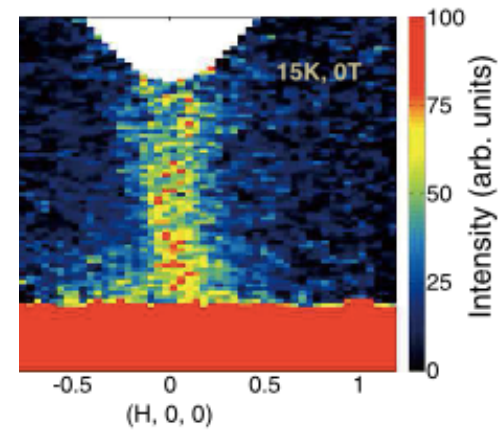




2K 0T

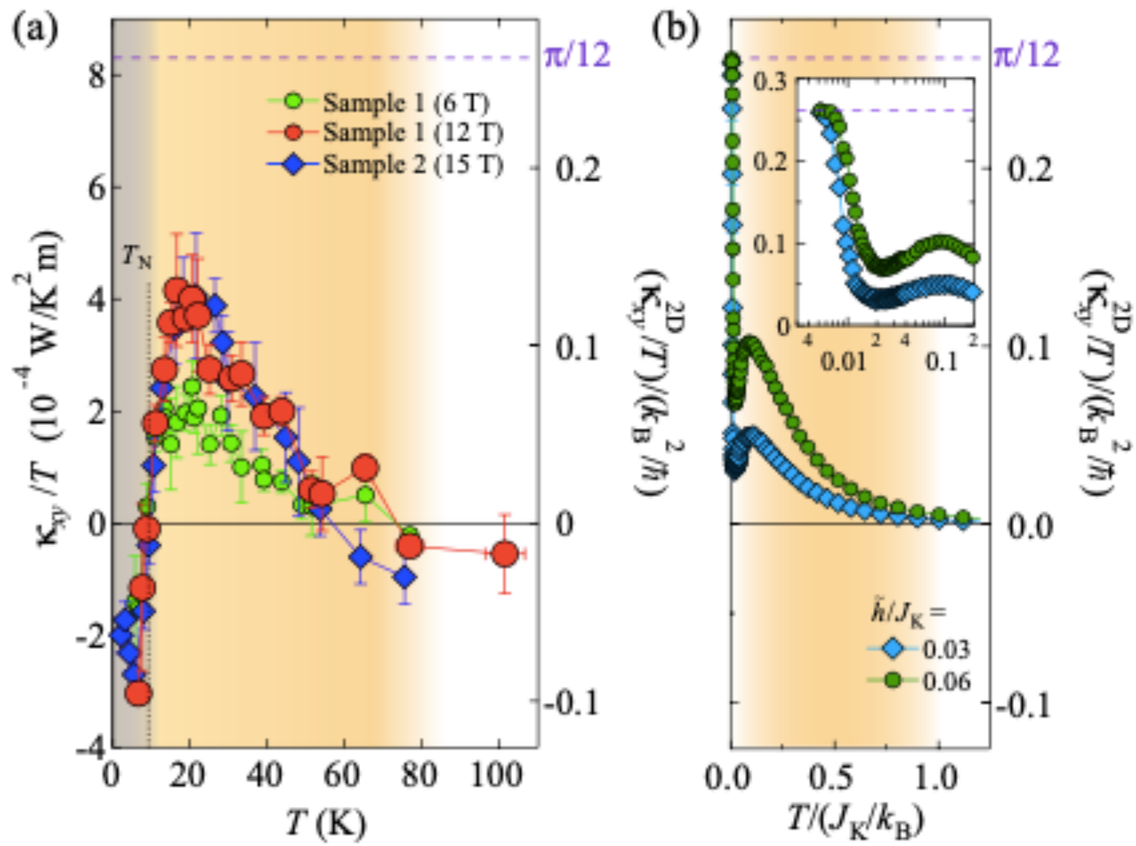


2K 8T



15K 0T

Thermal Hall Conductivity
(Magnetic Field Perpendicular to ab plane)



Experiment

Theory

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