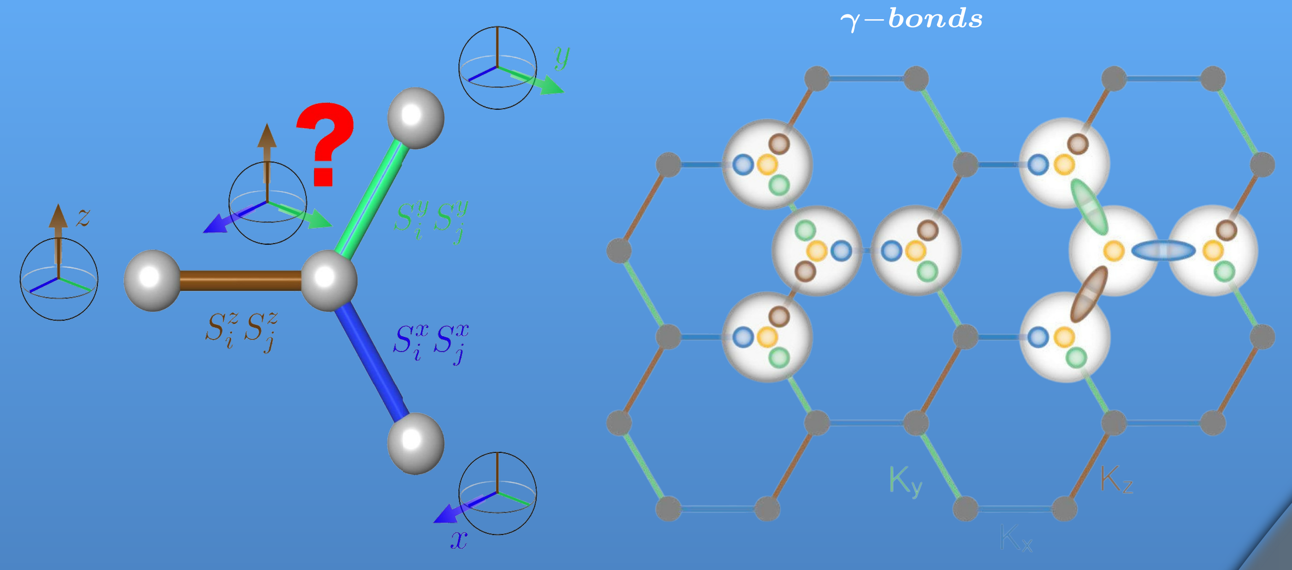
Evidence for gapless quantum spin liquid in a hoenycomb lattice

C. P. Tu *et al.*, arxiv:2212.07322 (2022)

Introduction

Kitaev honeycomb model $H_{Kitaev} = -\sum_{\gamma-bonds} K_\gamma S_i^\gamma S_j^\gamma$

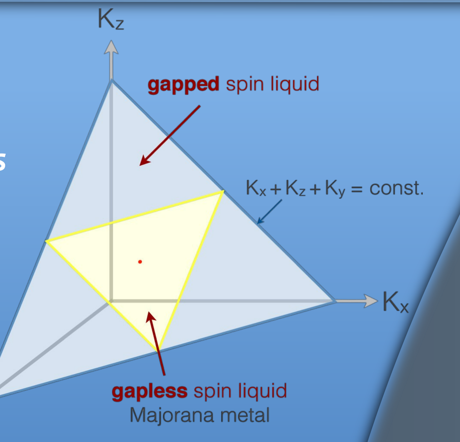


Anisotropic interaction → Exchange interaction frustration[1]

Kitaev quantum spin liquid

★ *Gapless phase carries gapped vortices (visons) and gapless spinons*

★ *Gapless phase acquires a gap in the presence of a magnetic field and converts into a gapped non-Abelian ohase hosting Majorana edge modes*

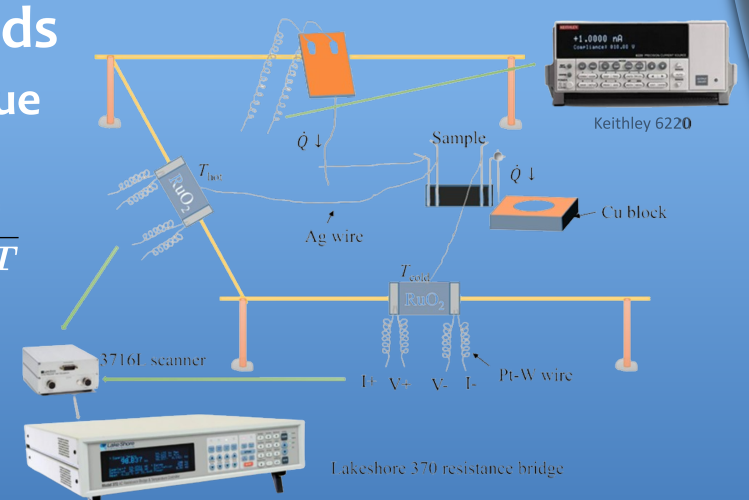


Phase diagram of Kitaev model

Methods

Technique

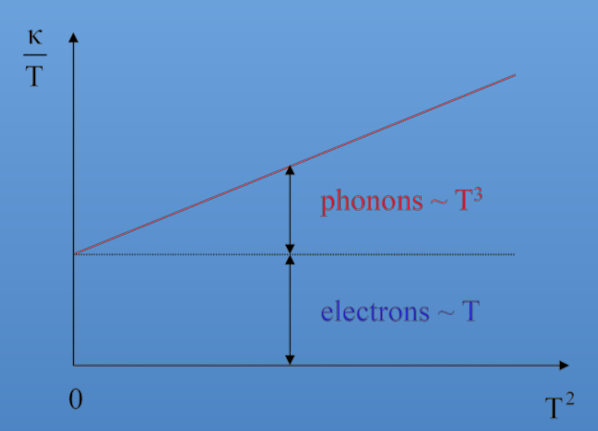
$$\kappa = \frac{L\dot{Q}}{A\Delta T}$$



Ultralow-temperature thermal conductivity

→ a bulk tool to probe low-energy quasiparticles

$\kappa = \kappa_{electron} + \kappa_{phonon} + \kappa_{magnon} + \kappa_{spinon}$



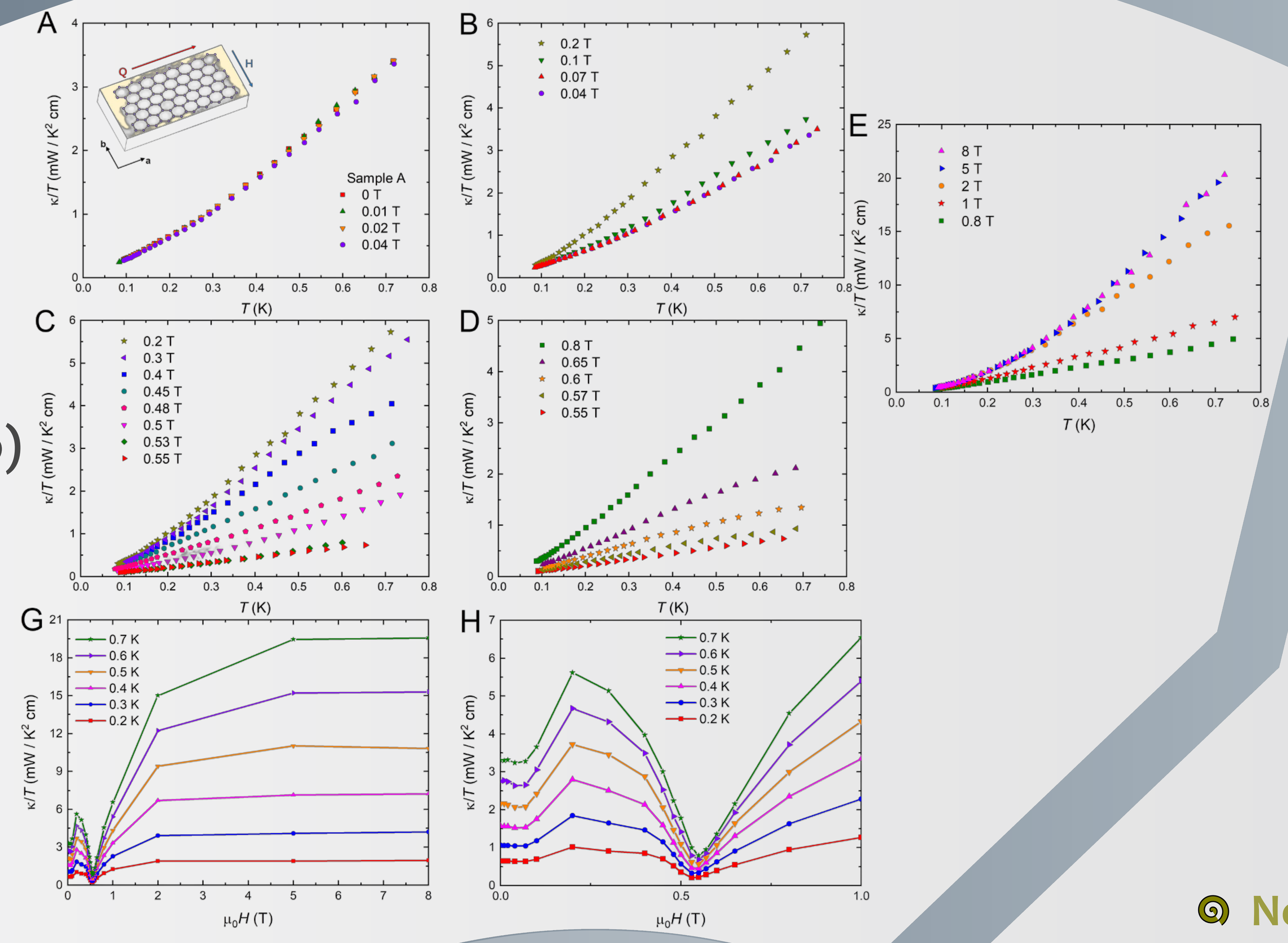
$$\kappa = \frac{1}{3}Cvl$$

FERMIONS (Electrons) $\kappa \propto C_e \propto T$ — spinons

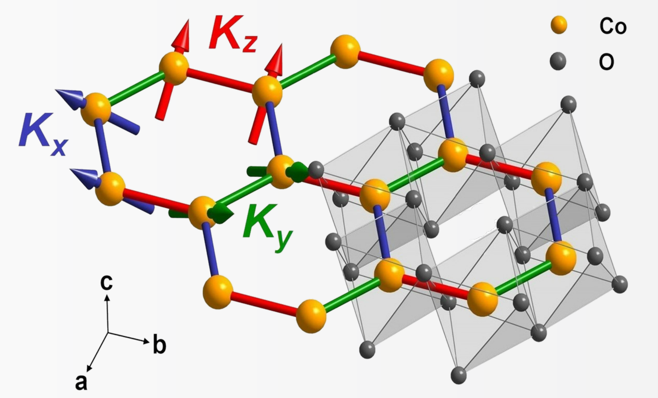
BOSONS (Phonons) $\kappa \propto C_{ph} \propto T^3$ — magnons

$\kappa/T = A + BT^2$

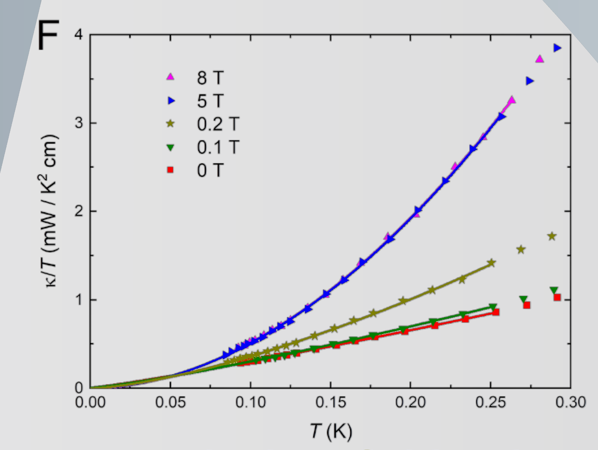
Field dependence of thermal conductivity (H || b)



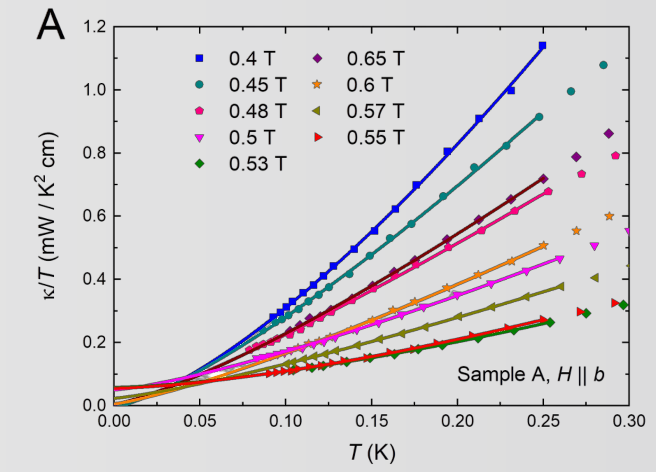
Crystal structure of $BaCo_2(AsO_4)_2$



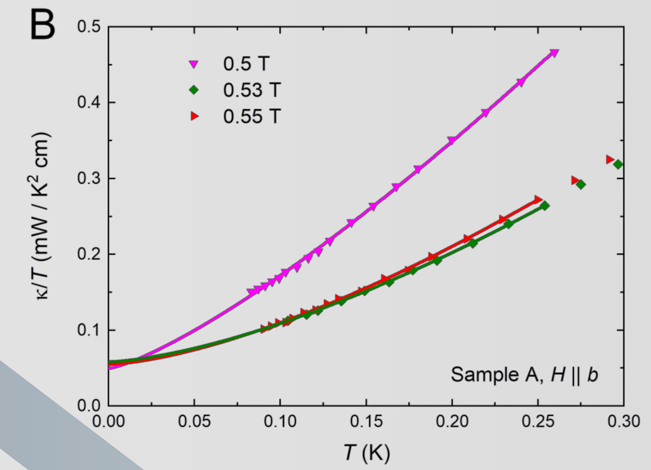
Residual linear term



No κ_0/T in the low-field ordered state and the high-field polarized state



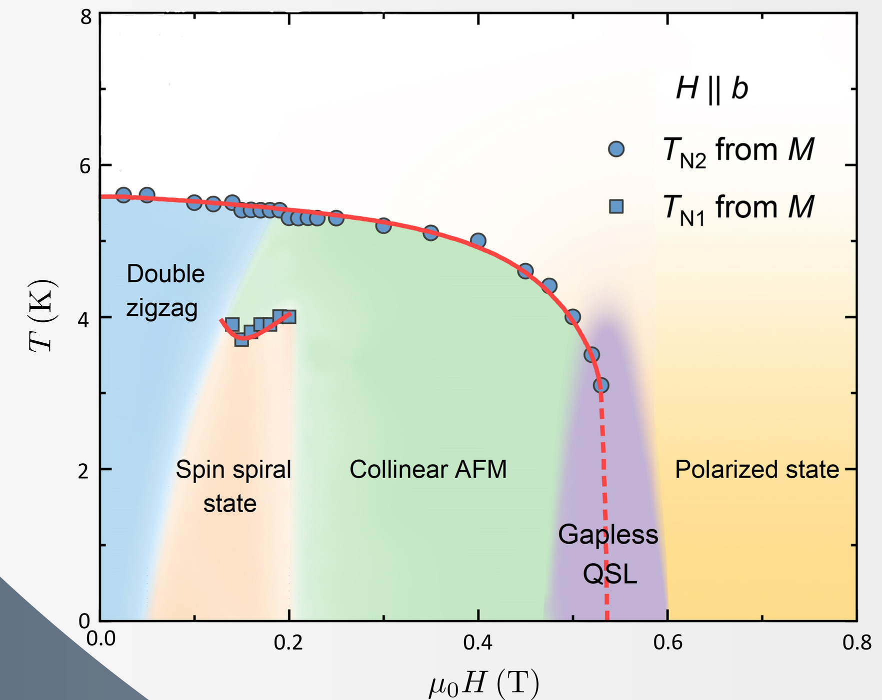
★ Finite κ_0/T when the magnetic order is nearly suppressed → Itinerant spinons



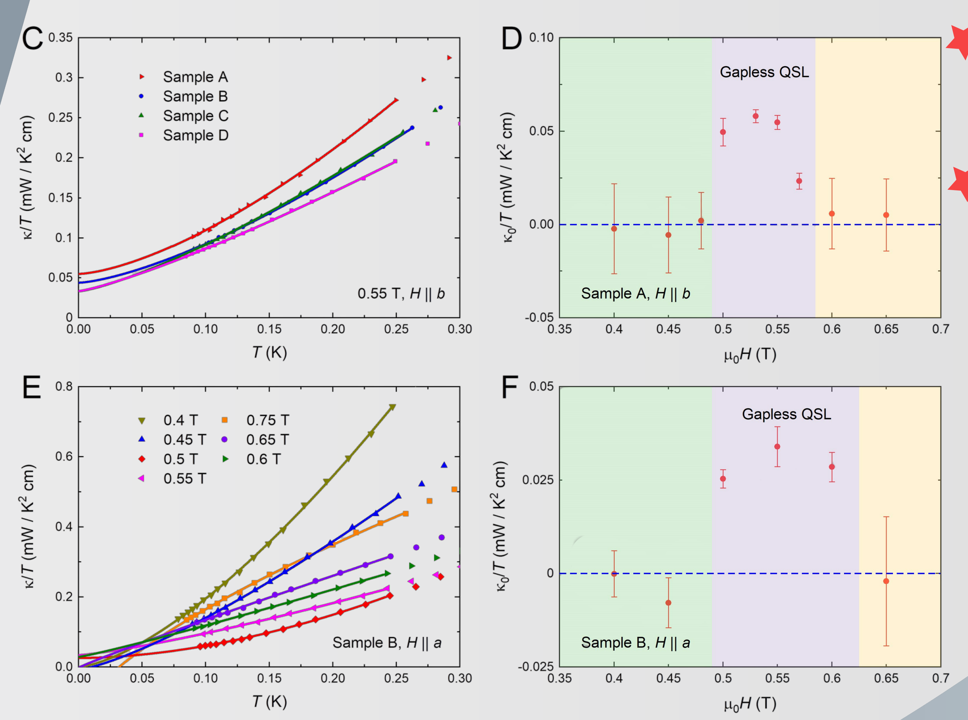
Mean free path ~43 interspin distance

Magnetic phase diagram

→ A gapless quantum spin liquid state exists in the intermediate field regime



Thermal conductivity along two crystallographic axes



★ Highly reproducible

★ Finite κ_0/T remains in both H || a and H || b

Motivation

Up to now, the researches of Kitaev materials are limited in $4d^5$ Ir^{4+} and $5d^5$ Ru^{3+} systems. Recently, it was proposed that the honeycomb-lattice cobaltate with $3d^7$ Co^{2+} in an octahedral crystal field environment is another potential platform to host Kitaev QSL[2]. Verifying the feasibility of this novel mechanism will certainly help understand this exotic but elusive field-induced phenomena in Kitaev materials and promote the pursuit of QSLs.

$BaCo_2(AsO_4)_2$ is one of the candidates. Although it undergoes a magnetic transition at 5.4K, thermodynamic measurements indicate that fields can suppress the magnetic order[3] and a field-induced spin-liquid like broad continuum was observed in the recent THz spectroscopy experiments[4]. However, recent inelastic neutron scattering studies were in favor of the XXZ-J1-J3 model instead of dominant Kitaev interactions in BCAO[5].

Whether Kitaev model or QSL state is feasible in BCAO and even more generally in cobaltates still remains controversial.

To address the issue, more information by ultralow-temperature thermal conductivity measurements can help understand the magnetic excitations and the nature of its ground state.

Discussion

Possible scenarios:

◎ *Z2 Gapless Kitaev spin liquid* ✗

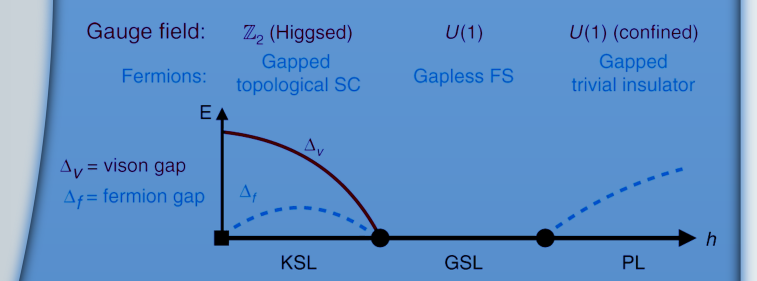
Within the framework of pure Kitaev model, the itinerant Majorana fermions are gapless with two Dirac nodes. When applying fields, the gapless KQSL phase acquire a gap

$$\Delta_M \sim \frac{h_x h_y h_z}{K^2}$$

Due to the particular geometry and the oxygen-mediated hopping process, the Majorana gap equals to zero if and only if H || b.

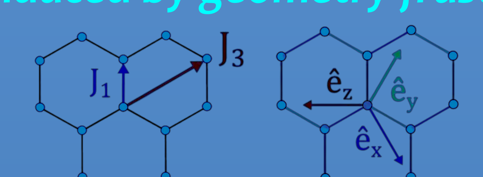
→ *In contrast with results !*

★ *U(1) Gapless quantum spin liquid with spinon Fermi surfaces*



→ *In analogy to $p_x + ip_y$ superconductor*

★ *U(1) Gapless quantum spin liquid induced by geometry frustration*



→ *The competition between J1 and J3 is a feasible way to induce geometry frustration, thus approaching the gapless QSL state.*

Summary

1. Finite residual linear terms of thermal conductiviy are observed in a narrow in-plane field range after the order is nearly suppressed, which strongly indicates the presence of a field-induced gapless QSL state with mobile spinons.

2. The gapless QSL state remains stable no matter fields are applied perpendicular or parallel to the zigzag direction. It is incompatible with pure Kitaev model, more likely a frustrated QSL from the XXZ-J1-J3 model.

References

[1] S. Trebst *et al.*, Phys. Rep. 950, 1 (2022). [2] H. Liu *et al.*, Phys. Rev. Lett. 125, 047201 (2020).
[3] R. Zhong *et al.*, Sci. Adv. 6, eaay6953 (2020). [4] X. Zhang *et al.*, Nat. Mater. 22, 58 (2023).
[5] T. Halloran *et al.*, Proc. Natl. Acad. Sci. USA 120, e2215509119 (2023).