Signatures of fractionalization in spin liquids from interlayer thermal transport

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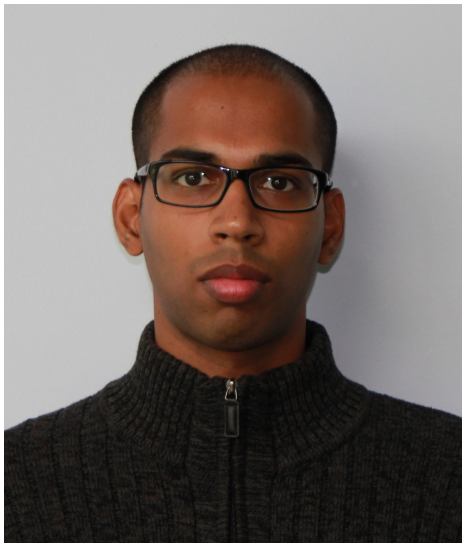
In collaboration with:



Yochai Werman,
Weizmann Inst.

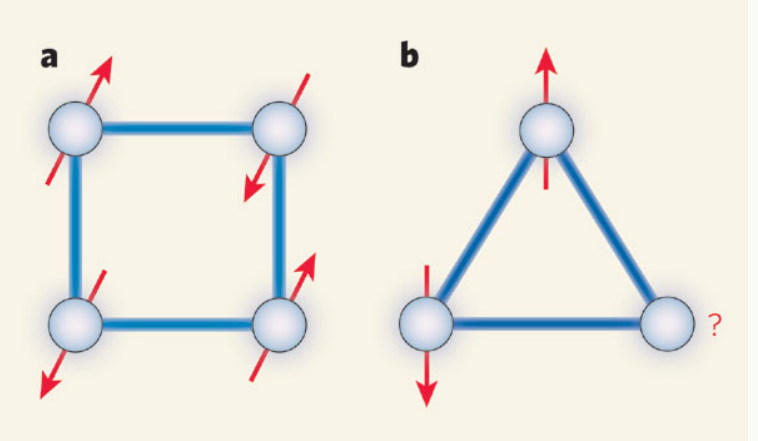
Sid Morampudi,
PKS Dresden/Boston U.

Erez Berg,
Weizmann/U. Chicago

Y. Werman, *S. Chatterjee*, S. Morampudi and E. Berg (arXiv:170x.xxxxx)

Quantum Spin liquids

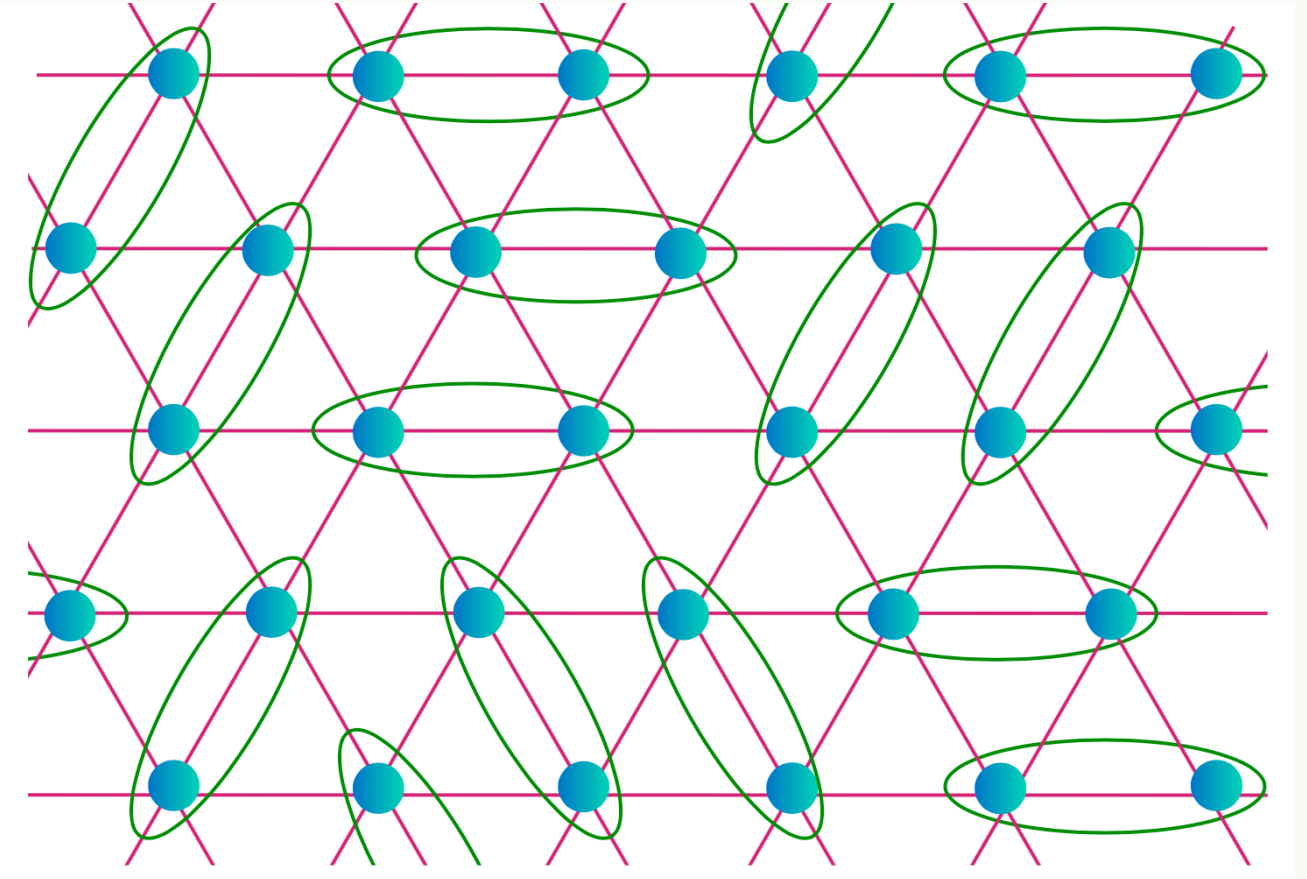
- Traditional quantum magnetism: Ordered ground states with broken symmetry (Eg: Antiferromagnet)



- Geometric frustration: Additional possibilities

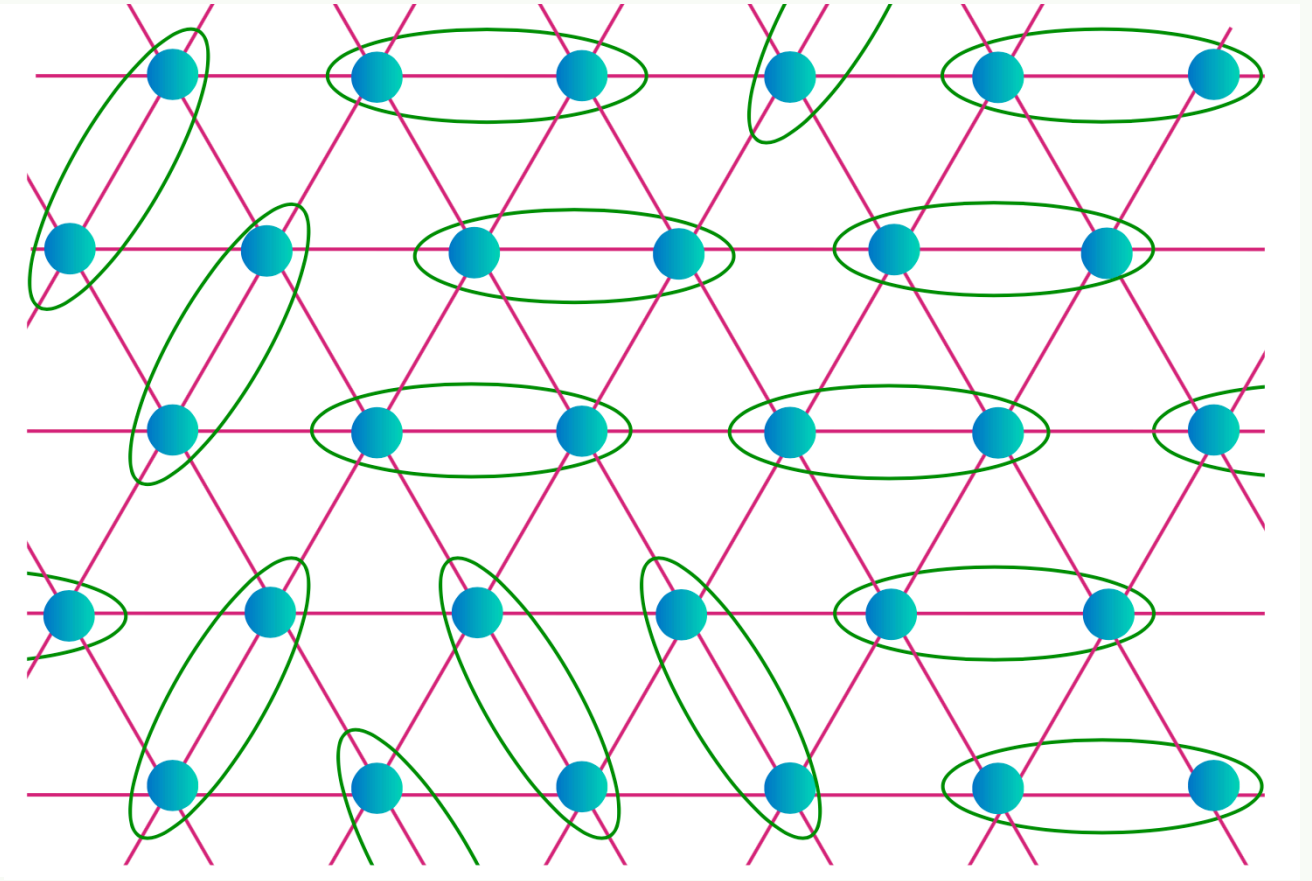
- Spin liquids: Mott insulators with no broken symmetry due to quantum fluctuations

Quantum Spin liquids



Anderson 1973, 1987; Kivelson, Rokhsar 1987; Wen 1991, Sachdev 1992, and a lot of others. Figure: S. Sachdev (Harvard)

Quantum Spin liquids



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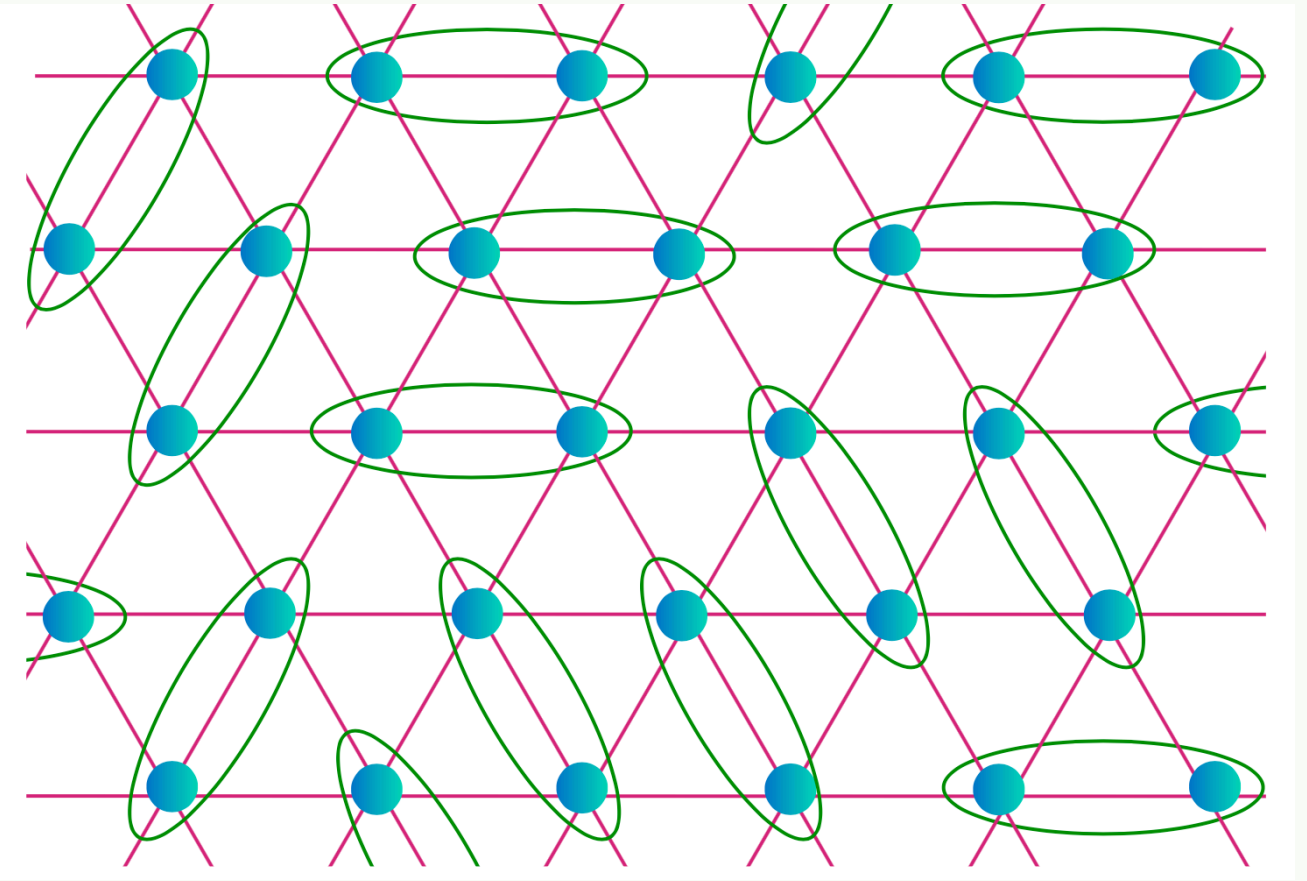
Quantum Spin liquids



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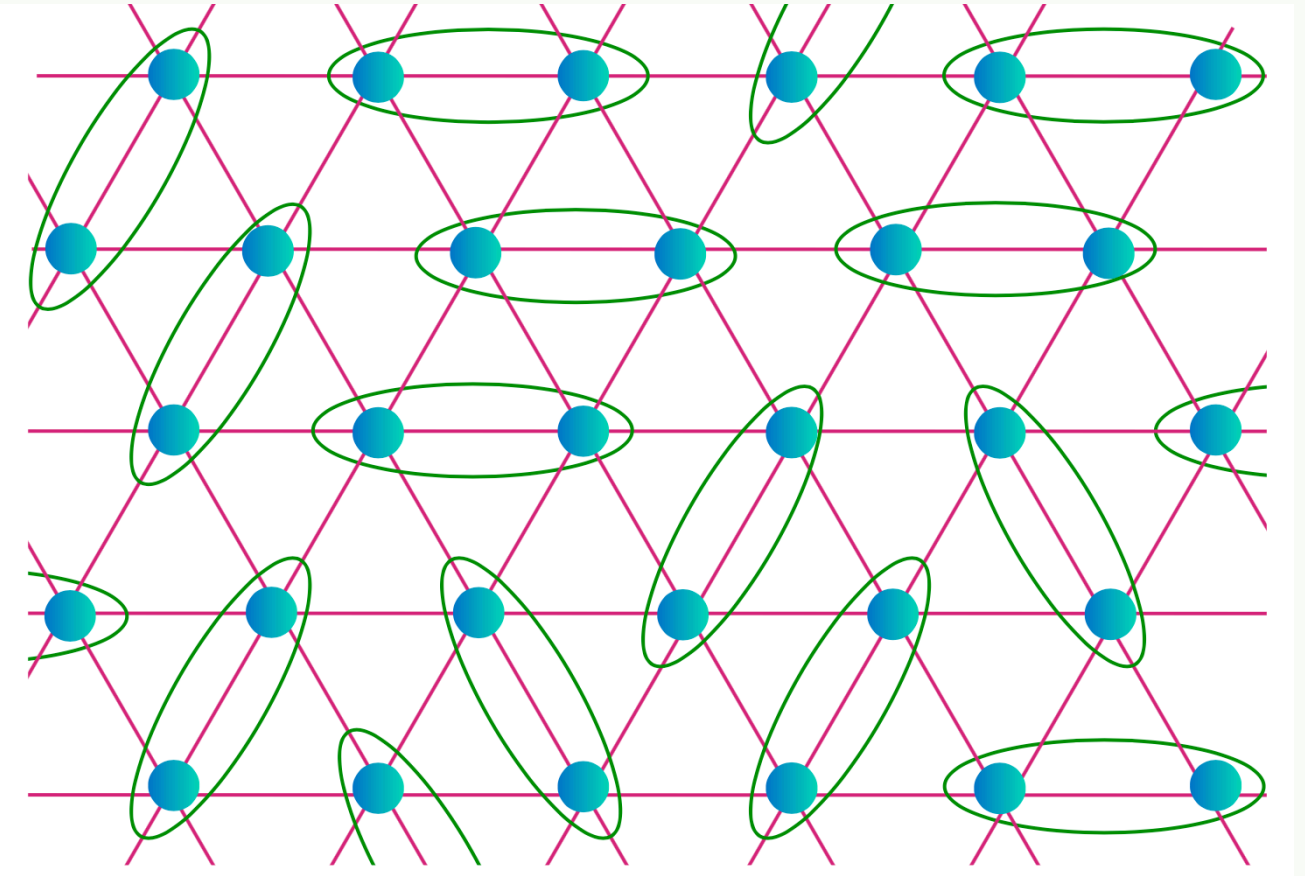
Quantum Spin liquids



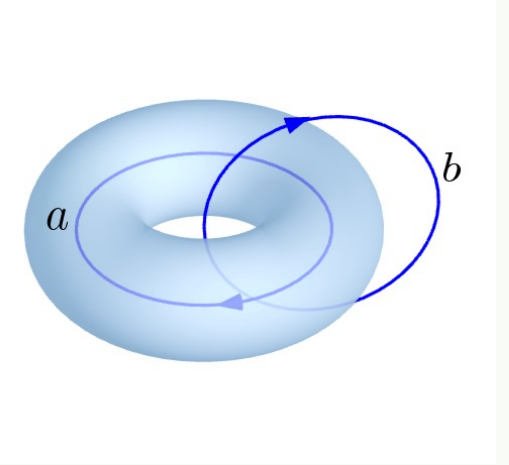
Anderson 1973, 1987; Kivelson, Rokhsar 1987; Wen 1991, Sachdev 1992, and a lot of others. Figure: S. Sachdev (Harvard)

Defining Quantum Spin liquids

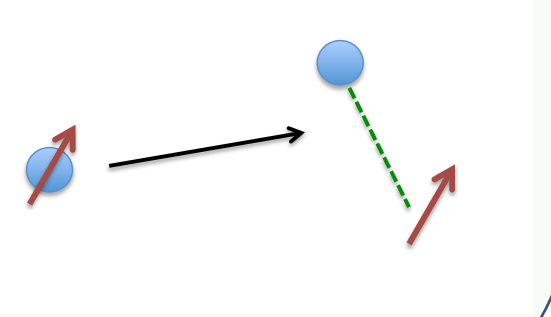
- How can we define spin liquids more precisely?

- Long range quantum entanglement

- 4-fold g.s. degeneracy on a torus (topological order)



- Excitations which carry fractional quantum number (S = ½ spinons) coupled to emergent gauge fields.



Figures: Barkeshli *et al*, arXiv: 1410.4540, E. Berg (U. Chicago)

Detecting Quantum Spin liquids

- Experimental signatures:
- No magnetic order down to very low temperatures

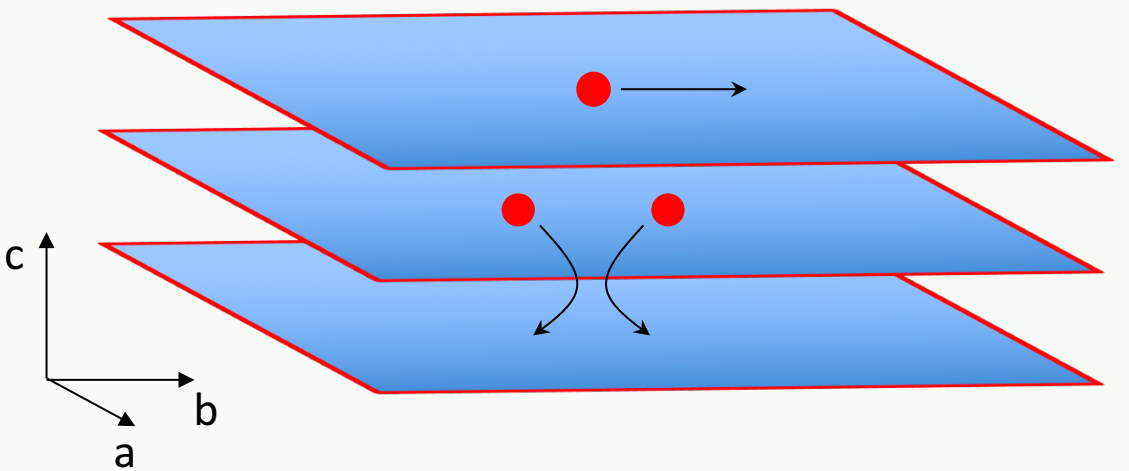
- Can we probe fractionalization directly?
- Previous work: Neutron scattering, spin injection, coherent tunneling into superconductors…

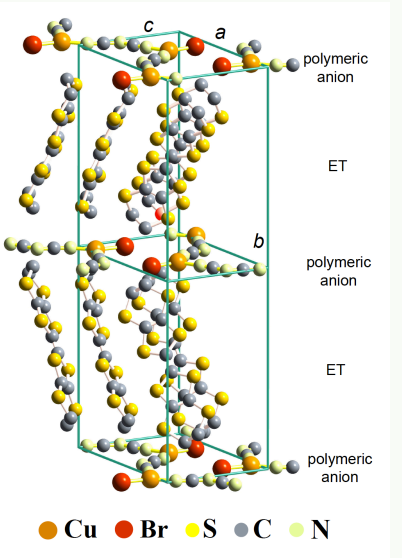
  Morampudi *et al*, arXiv:1608:05700, *S. Chatterjee et al*, PRB **531**, 210 (2015), Barkeshli *et al,* Science **346**, 6210 (2014)

- **This talk: Temperature dependent anisotropy of thermal conductivity in gapless QSLs**

Detecting QSLs: Thermal transport

- Why thermal transport:
- Many proposed QSLs are layered materials, with possibly gapless charge-neutral spinons
- κ_c and κ_{ab} show parametrically different behavior as a function of temperature

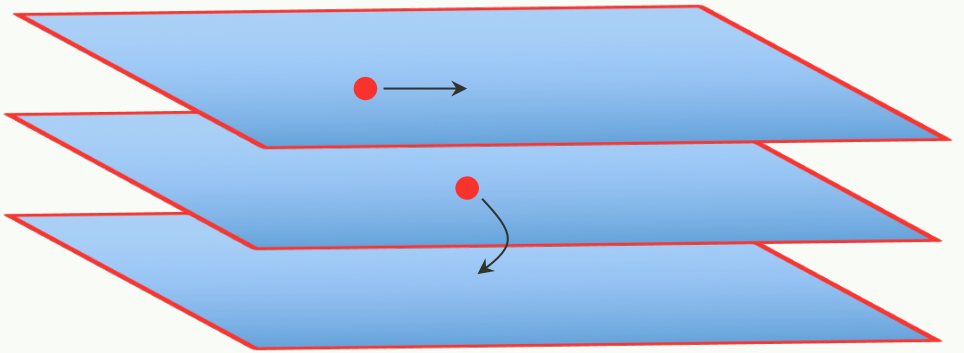


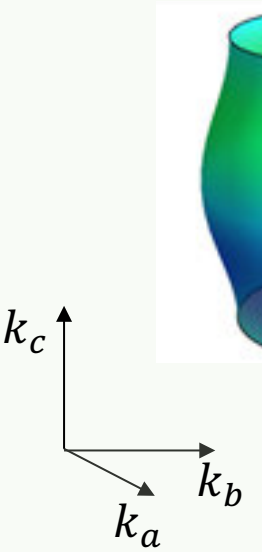


Figures: E. Berg (U. Chicago), De Souza *et al*, J Phys. CM, **27** (2015)

Detecting QSLs: Thermal transport

- Why thermal transport:
- Contrast with an anisotropic metal having non-fractionalized excitations (electrons)





At low temperatures , $\frac{\kappa_{ab}}{\kappa_c} \rightarrow const \gg 1$

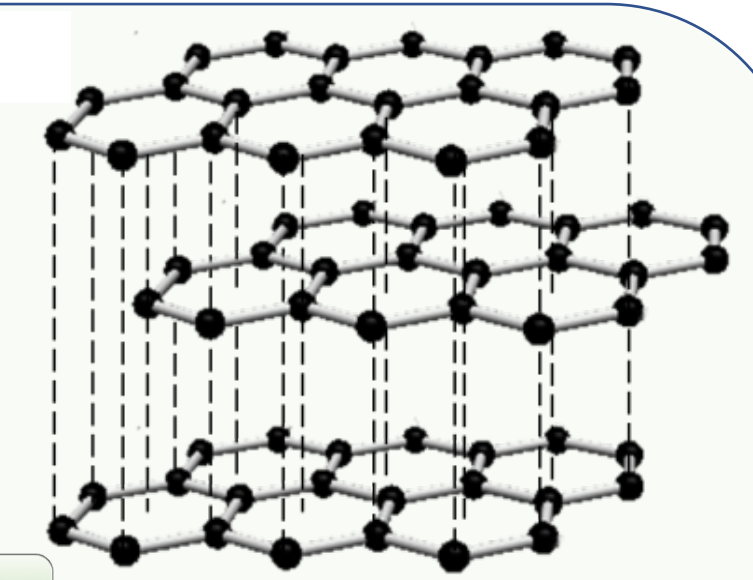
Figures: E. Berg, U. Chicago

Detecting QSLs: Thermal transport

- Model and results:

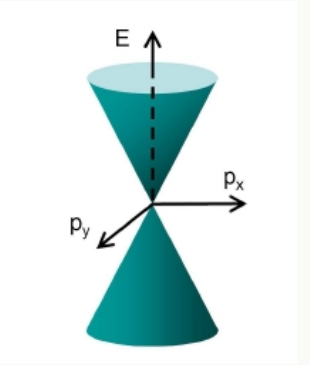
Weakly coupled stacks of Kitaev's honeycomb model

A. Kitaev, Annals of physics **321** (2006)

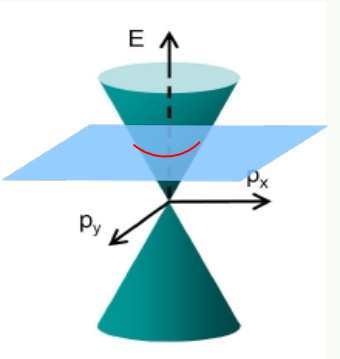


Distinguishing feature: Time reversal symmetry

- TRS preserved: Dirac cones



- TRS broken: Fermi surface



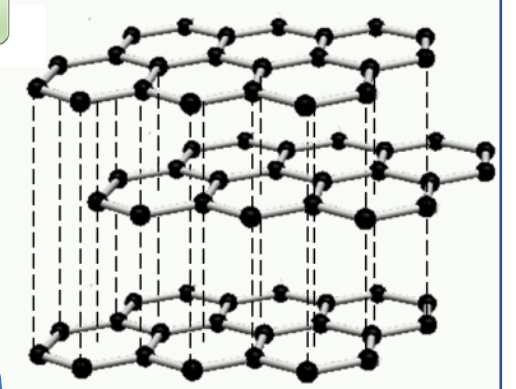
Figures: E. Berg

Detecting QSLs: Thermal transport

- Model and results:

Weakly coupled stacks of Kitaev's honeycomb model

TRS disorder acts as random vector potential



	In-plane		c-axis	
	Clean	Disordered	Clean	Disordered
Z_2 Dirac	T [1]	T	T^5	$T^{5-\alpha}$
Z_2 FS	∞	T	T^3	T^2
$U(1)$	$T^{1/3}$ [2]		$T^{5/3}$	T^2

Dominated by phonons

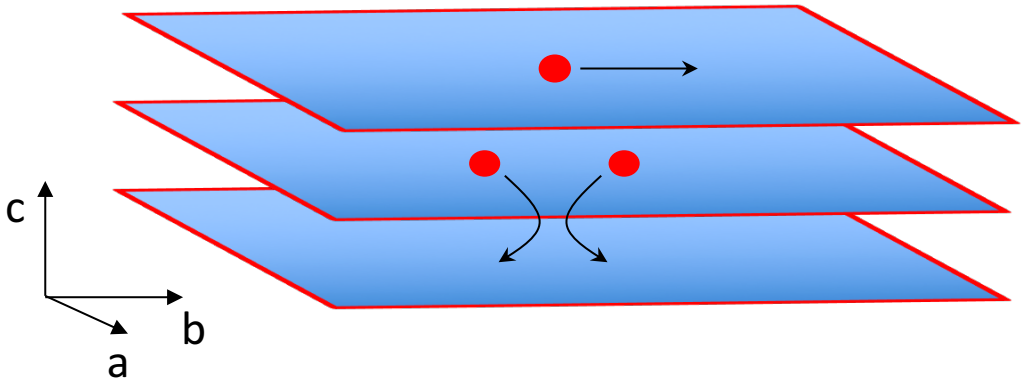
Dominates phonons

From interlayer gauge-coupling

[1] Durst and Lee, PRB 62, 1270 (2004), Nave and Lee, PRB 76, 235124 (2007)

Summary

Parametrically different in-plane vs interplane thermal transport can be a valuable probe of fractionalization in layered spin liquids.



Thank you for your attention!