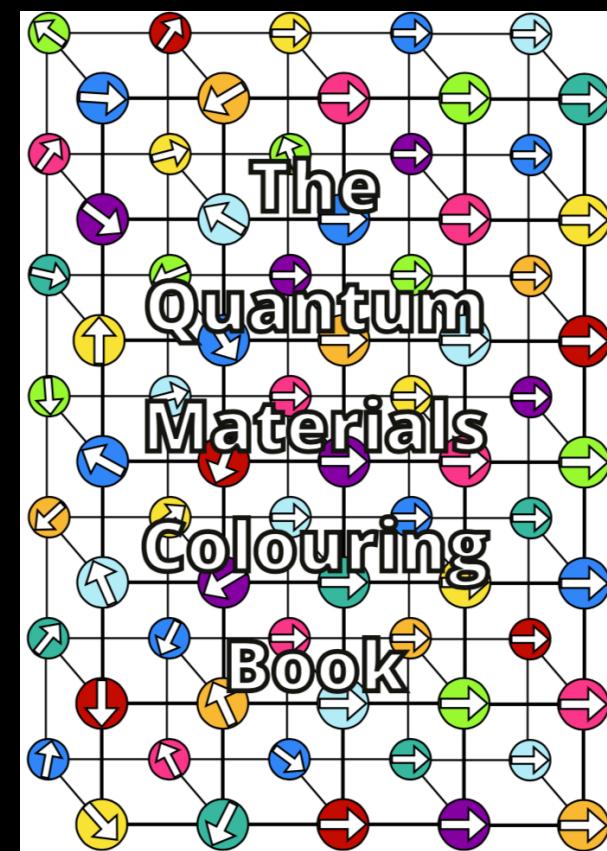


LEON BALENTS

# MAGNETISM AND MODEL SYSTEMS

QMS2019, Oxford



# WHY MAGNETS?

- Lots of emergent behaviors 😎
- Truly beyond band theory 🤠
- Description is often possible with just a few parameters (exchanges, anisotropies...) 🖌
- Ideal exploration of entanglement: start with local degrees of freedom and end up with singlets etc. 🍞

# THIS MORNING

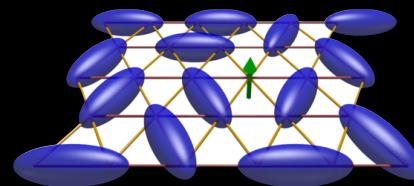
- Hide Takagi: Exotic spin-orbital entangled phases in 5d and 4d transition metal oxides
- Roser Valenti: Recent progress on field- and pressure-induced phases in spin-orbit coupled frustrated models and materials
- Chris Stock: Spin-wave directional anisotropies in langasite without antisymmetric exchange
- Chris Wiebe: High pressure routes to new pyrochlores and exotic magnetism
- Lucile Savary: Thermal conductivity in complex magnets

# DISCUSSION - THEMES

- Searching for quantum spin liquids in anisotropically interacting systems
- Hybrid systems: soft chemistry, VdW epitaxy...
- Anisotropy/directionality in conventional ordered magnets: spontaneous or chiral?
- Chirality and Hall effects

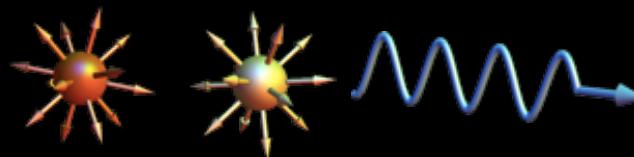
# SPIN LIQUIDS: WHAT THE THEORISTS DREAM OF

- Topological QSLs



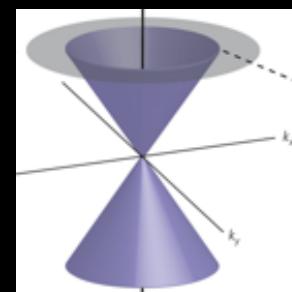
anyonic spinons

- U(1) QSL



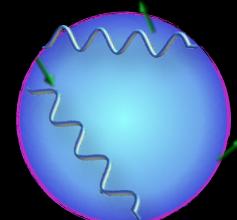
electric+magnetic monopoles, photon

- Dirac QSLs



strongly interacting Dirac fermions

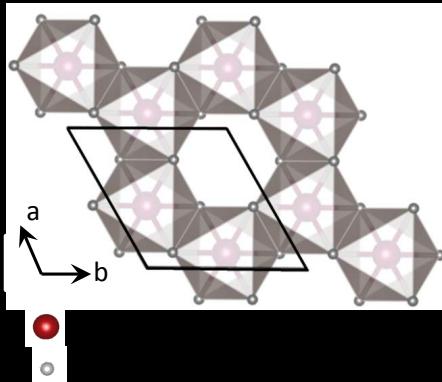
- Spinon Fermi surface



non-Fermi liquid "spin metal"

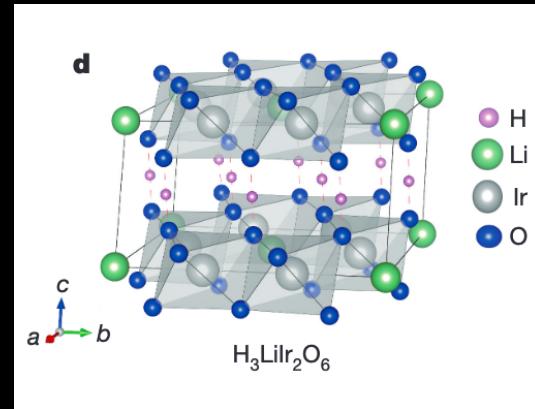
# DISCUSSION - THEMES

- Kitaev-motivated materials (Takagi, Valenti)



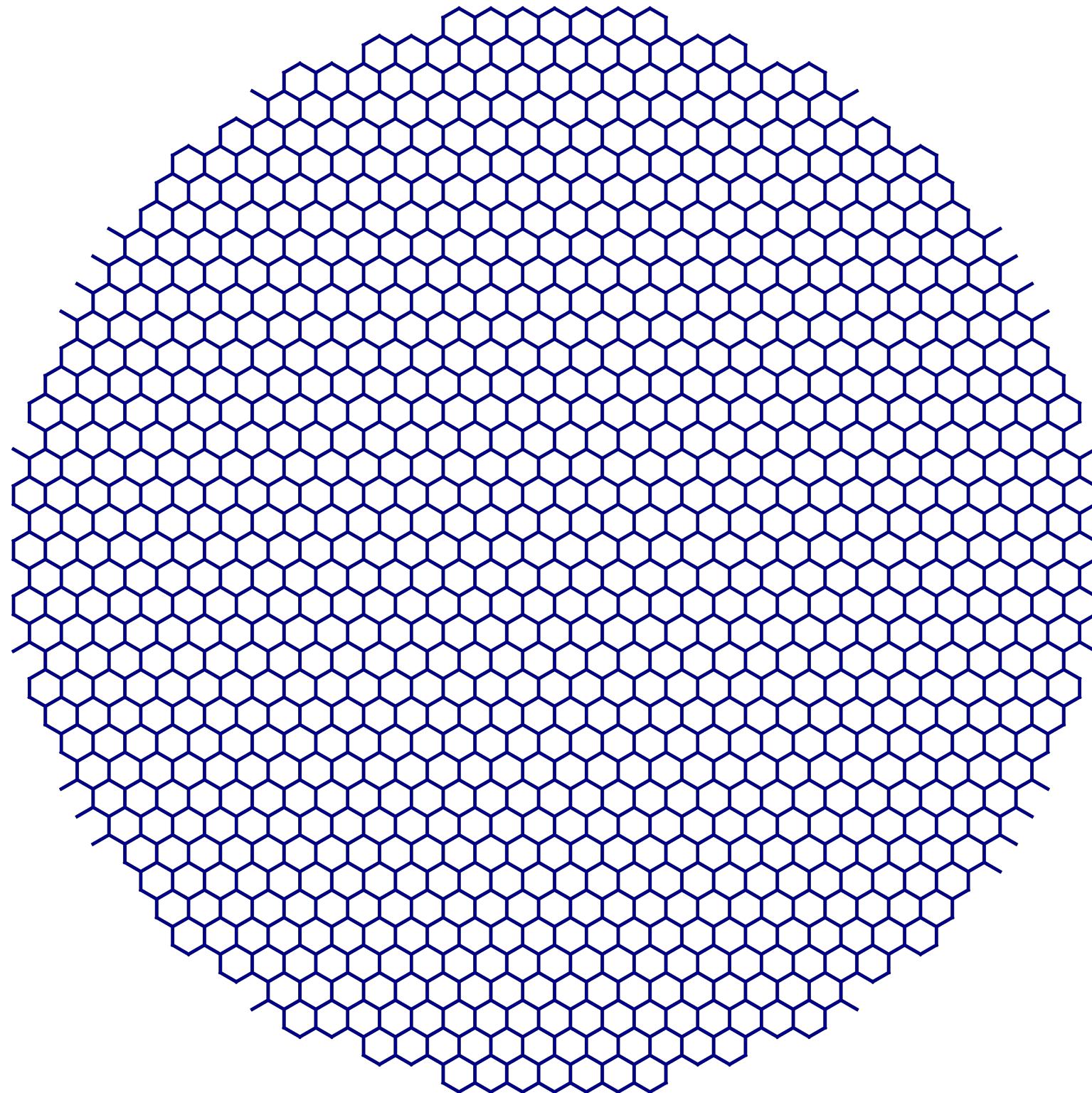
$\alpha$ -RuCl<sub>3</sub>

- Do these have anything to do with Kitaev spin liquid?
- Is there any QSL in RuCl<sub>3</sub> at all? Only one experiment seems to point to it.
  - If not, still very rich correlation region at  $B>10T$  or so. Do you understand all these bound states?
- In iridate, disorder seems important. Is there really a gap?  $1/T_1$ ?
- Might this be similar physics as in organic spin liquid materials?



# DISCUSSION - NEW DIRECTIONS

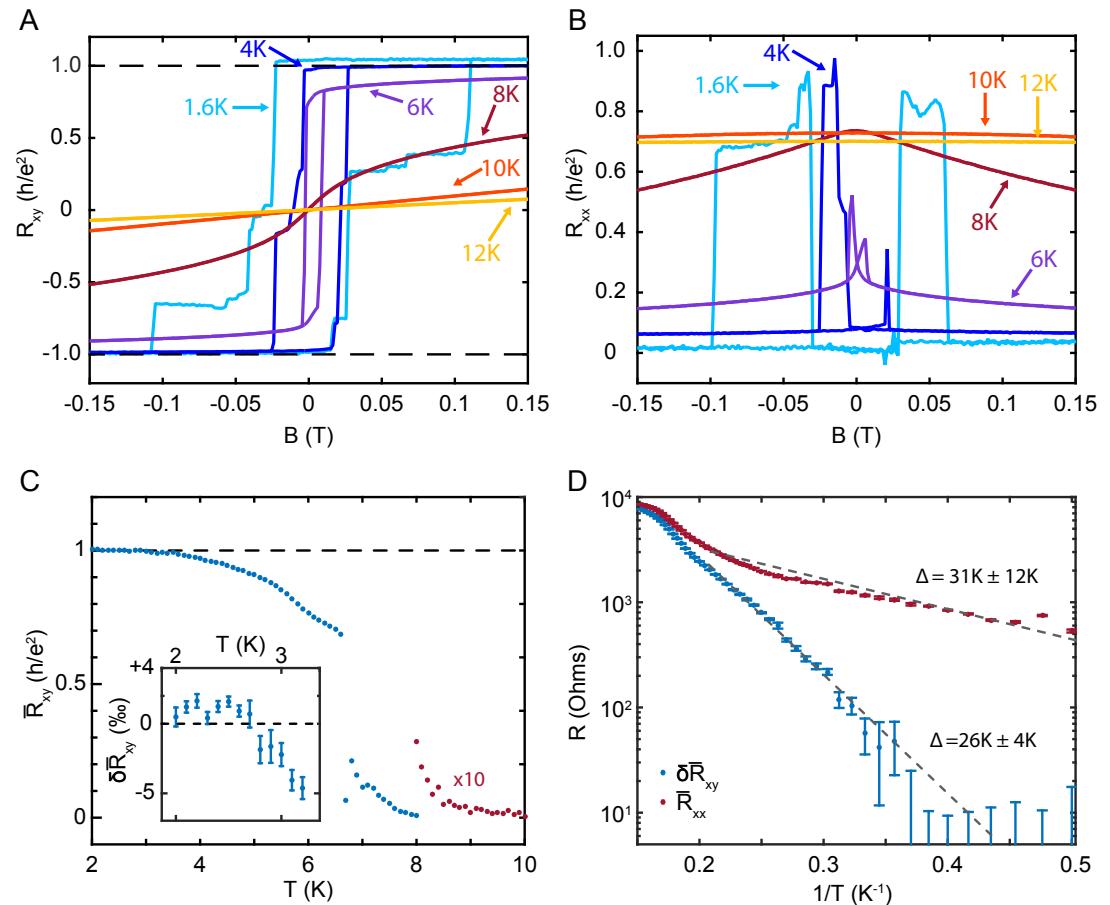
- Takagi:  $\text{Ag}_3\text{LiRu}_2\text{O}_6$  - pressure induced spin liquid?  
What was the starting state??
- Valenti: a- $\text{RuCl}_3$  on graphene. Conduction in the graphene presumably? How strongly are they coupled? Does Hall number agree with ab initio charge transfer?
  - Could we twist them?



# QAHE

Quantized to 1/1000

$n=3$



Serlin *et al*, 2019

First observation of FMism: A. Sharpe *et al*, Science (2019)

# DISCUSSION - NEW DIRECTIONS

- Twisted 2d materials?
  - People in this area working mainly on  $\text{MnPS}_3, \text{CoPS}_3, \text{NiPS}_3, \text{CrI}_3\dots$
  - Also  $\alpha\text{-RuCl}_3$ . Recall  $T_N$  seems to depend on stacking, suggests there is some interaction.

# DISCUSSION - NEW DIRECTIONS

- Stock: directional spin waves - made analogy to diode
  - is it good for something? Spintronics applications?
- Wiebe:  $\text{Lu}_2\text{Rh}_2\text{O}_7$  - unusual resistivity?
  - Non-metallic metallic spin liquid?
  - Q: Hall number? Metal or semimetal?

# THERMAL TRANSPORT

- Seems to be a powerful but complicated probe of magnetism
- How well can one separate phonon and spin contributions? High magnetic fields? Separate probes of phonon lifetimes directly?
- Is there a phonon Berry phase contribution? Postulated theoretically but not demonstrated to my knowledge.
- Savary: Can we get useful information from the phonon part?

# DISCUSSION - QUESTIONS

- How much do Kitaev materials actually have to do with the Kitaev model?
- Is spin-orbital entanglement restricted to 4d and 5d? Examples in 3d TMs?
- How to detect the entanglement directly?
- How are these talks connected?