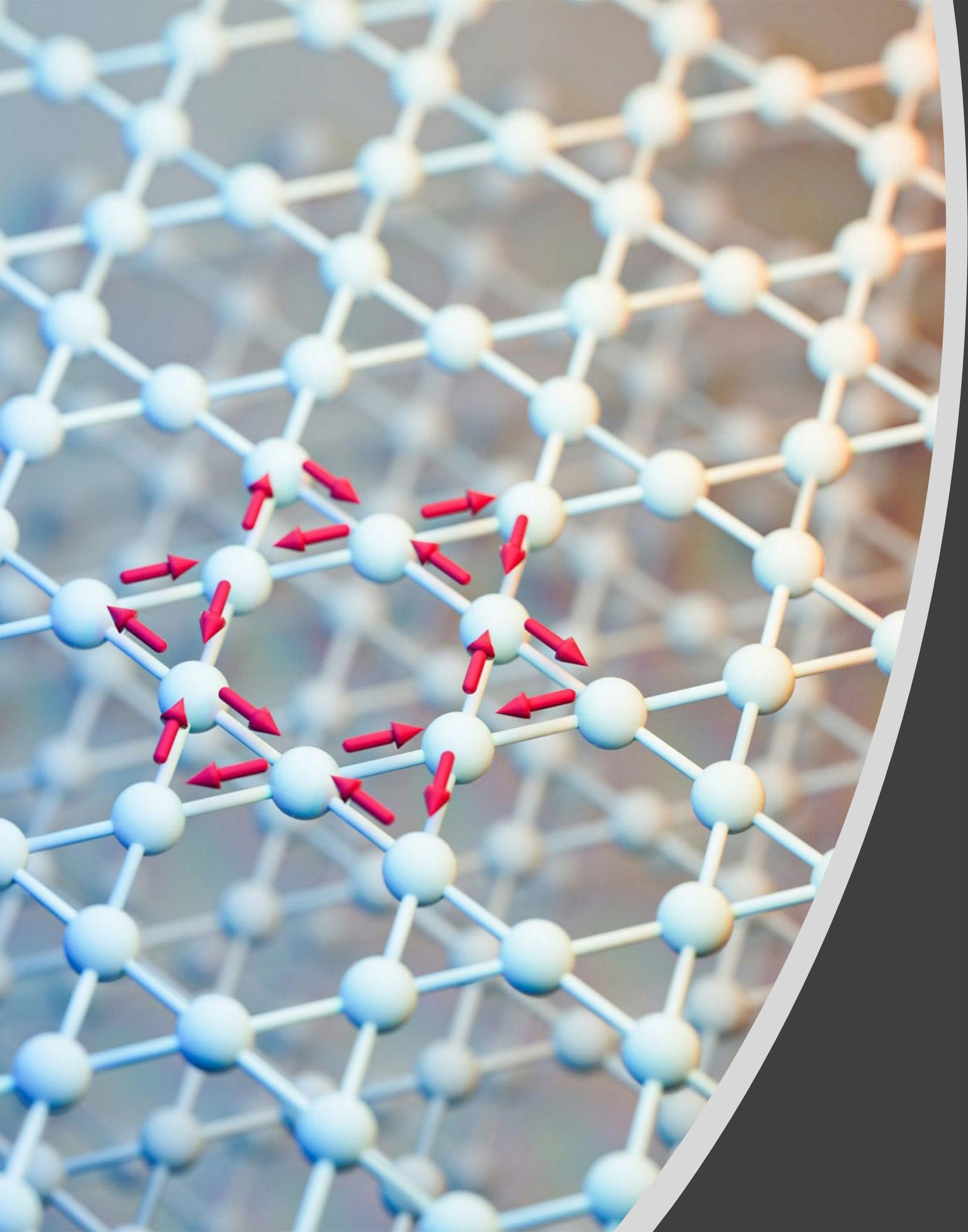


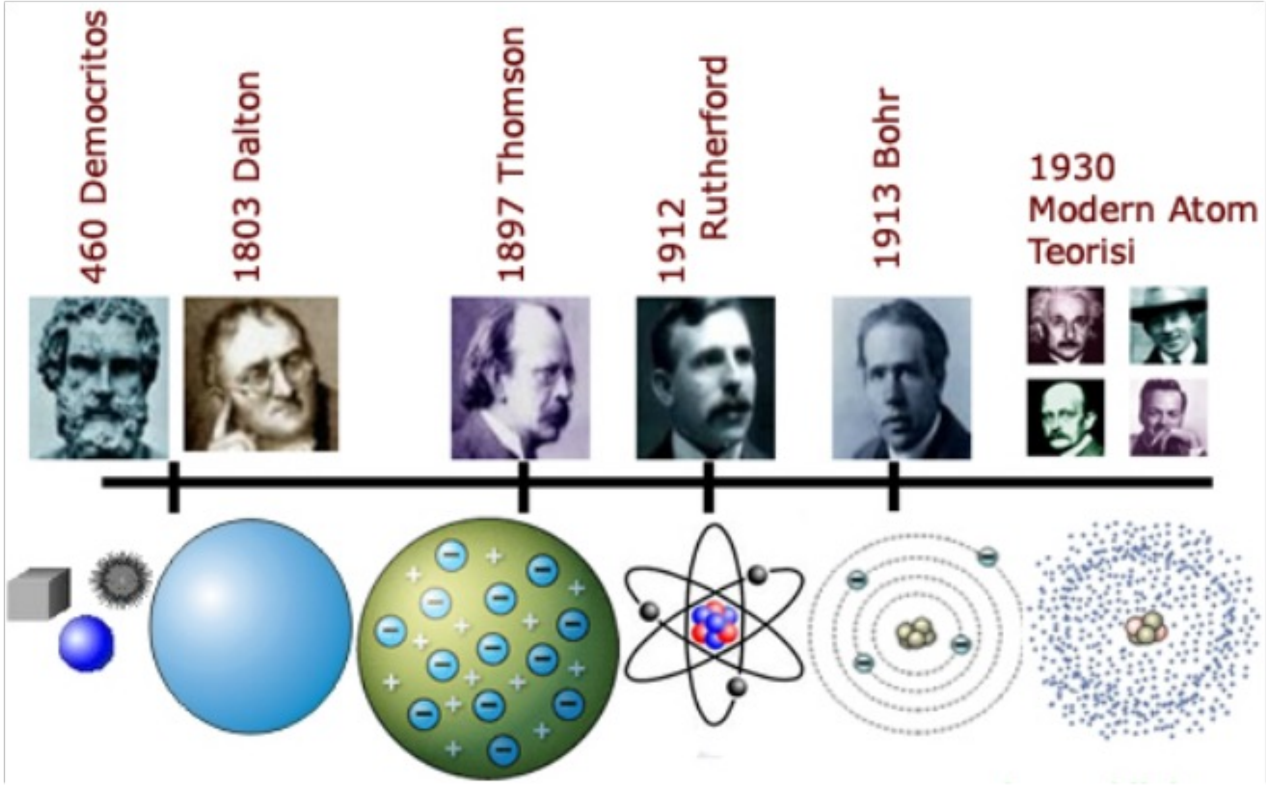
Kagome Networks and Frustration

Andrea Capa Salinas
Matrl 286G
05/31/2022

Emergent Phenomena

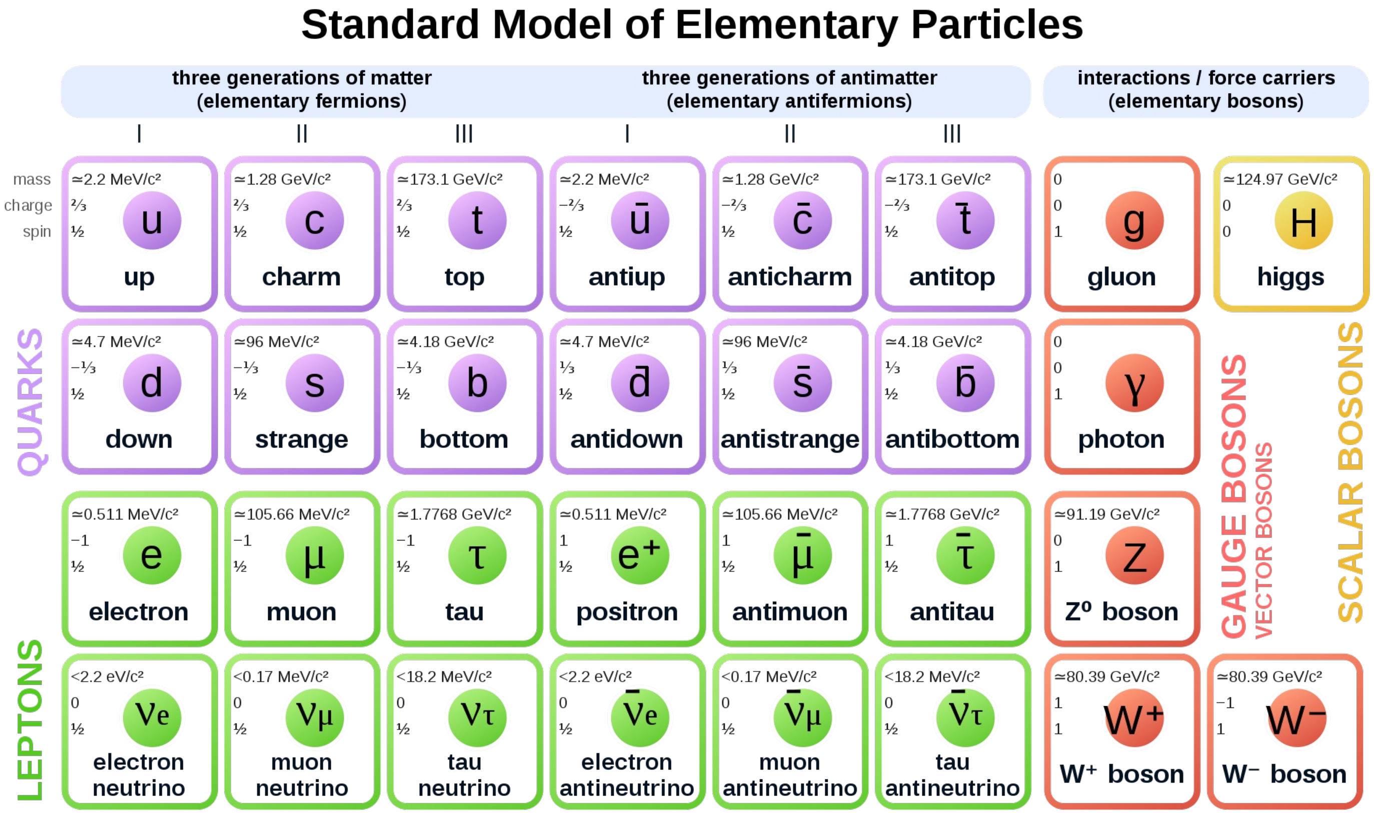
An entity exhibits properties its parts do not possess on their own

Reductionist Approach



https://saintschemistry10.weebly.com/history-of-the-atom.html

Reductionist Approach

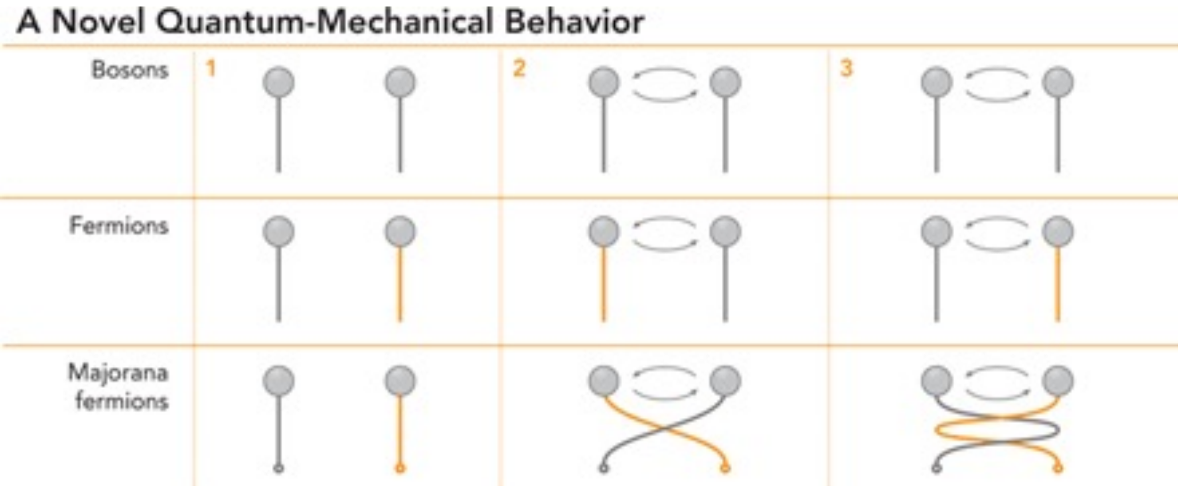


Standard Model of Elementary Particles

	three generations of matter (elementary fermions)			three generations of antimatter (elementary antifermions)			interactions / force carriers (elementary bosons)	
mass charge spin	I	II	III	I	II	III		
QUARKS	≃2.2 MeV/c² ⅔ ½ u **up**	≃1.28 GeV/c² ⅔ ½ c **charm**	≃173.1 GeV/c² ⅔ ½ t **top**	≃2.2 MeV/c² −⅔ ½ $\bar{u}$ **antiup**	≃1.28 GeV/c² −⅔ ½ $\bar{c}$ **anticharm**	≃173.1 GeV/c² −⅔ ½ $\bar{t}$ **antitop**	0 0 1 g **gluon**	≃124.97 GeV/c² 0 0 H **higgs**
	≃4.7 MeV/c² −⅓ ½ d **down**	≃96 MeV/c² −⅓ ½ s **strange**	≃4.18 GeV/c² −⅓ ½ b **bottom**	≃4.7 MeV/c² ⅓ ½ $\bar{d}$ **antidown**	≃96 MeV/c² ⅓ ½ $\bar{s}$ **antistrange**	≃4.18 GeV/c² ⅓ ½ $\bar{b}$ **antibottom**	0 0 1 γ **photon**	GAUGE BOSONS VECTOR BOSONS SCALAR BOSONS
LEPTONS	≃0.511 MeV/c² −1 ½ e **electron**	≃105.66 MeV/c² −1 ½ μ **muon**	≃1.7768 GeV/c² −1 ½ τ **tau**	≃0.511 MeV/c² 1 ½ e^+ **positron**	≃105.66 MeV/c² 1 ½ $\bar{\mu}$ **antimuon**	≃1.7768 GeV/c² 1 ½ $\bar{\tau}$ **antitau**	≃91.19 GeV/c² 0 1 Z **Z^0 boson**	
	<2.2 eV/c² 0 ½ ν_e **electron neutrino**	<0.17 MeV/c² 0 ½ ν_μ **muon neutrino**	<18.2 MeV/c² 0 ½ ν_τ **tau neutrino**	<2.2 eV/c² 0 ½ $\bar{\nu}_e$ **electron antineutrino**	<0.17 MeV/c² 0 ½ $\bar{\nu}_\mu$ **muon antineutrino**	<18.2 MeV/c² 0 ½ $\bar{\nu}_\tau$ **tau antineutrino**	≃80.39 GeV/c² 1 1 W^+ **W^+ boson**	≃80.39 GeV/c² −1 1 W^- **W^- boson**

Emergent Phenomena in Kagome Networks

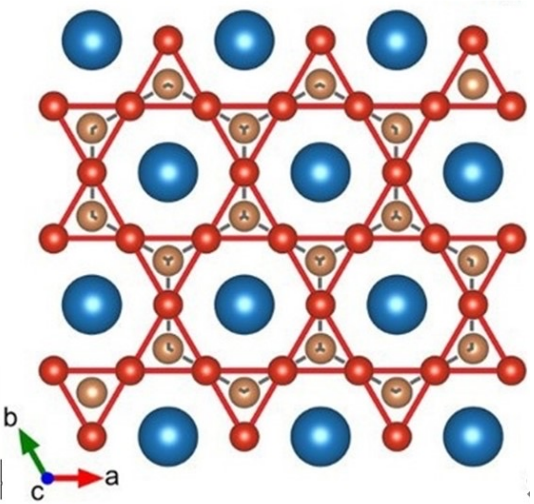
- Fractional Quantum Hall Effect
- Quantum Spin Liquid States
- Spinons
- Majorana fermions



Service R. F. (2011). Search for Majorana fermions nearing success at last?. Science. 332(6026), 193–195.

Kagome Networks

- Intersecting webs of “corner-sharing triangles”
- Named after patterned bamboo basket
  - Bamboo-basket (kago) woven pattern (me)



https://english.cas.cn/newsroom/research_news/phys/202112/t20211217_294587.shtml

Kagome Networks

- Lars Onsager (1944) paper on square lattice ising model
- Kodi Husimi and Itiro Syôzi (1950) simplified Onsagers solutions and solved for honeycomb and triangular
- Syôzi (1951) studied Kagome lattice

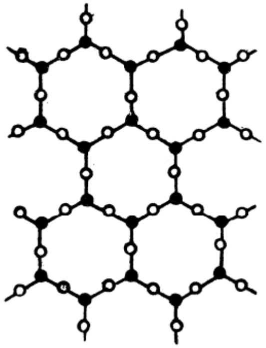


Fig. 2. Decorated Honeycomb Lattice

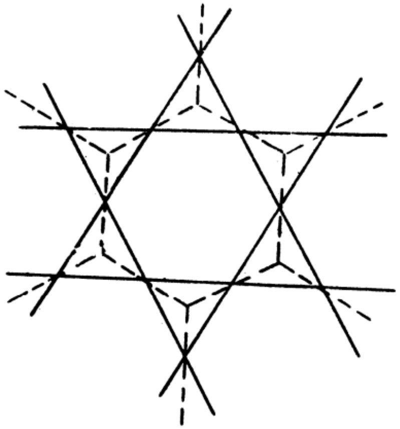
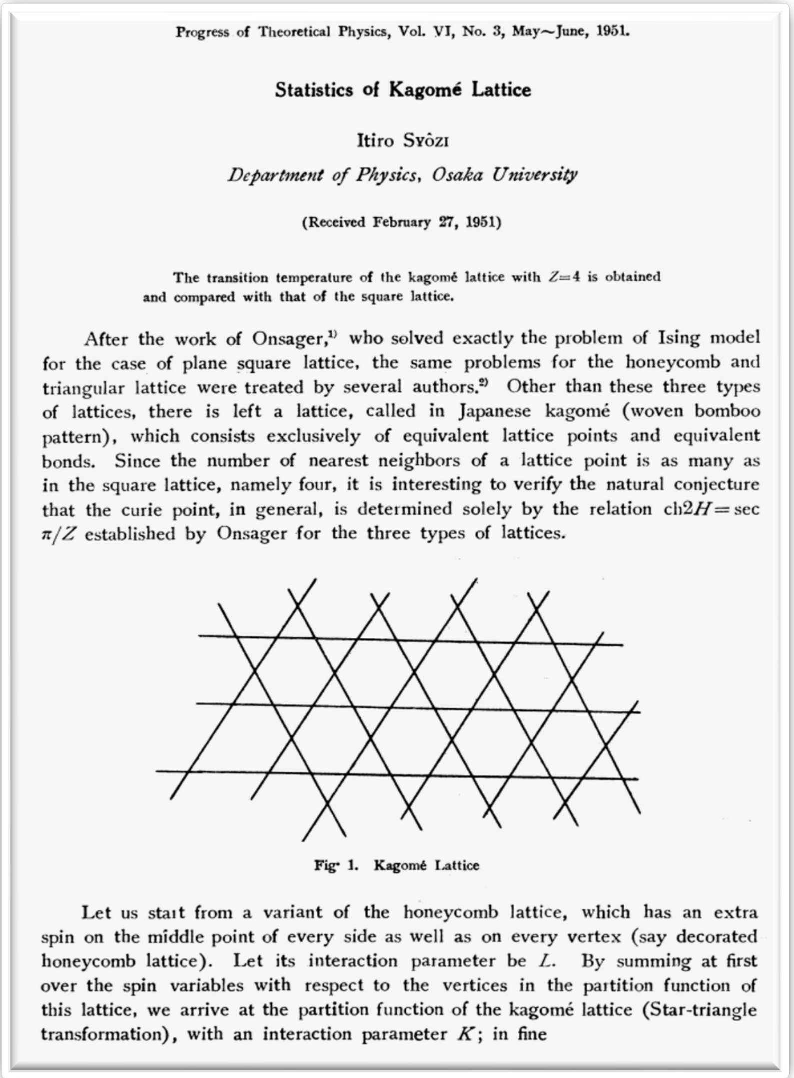


Fig. 3. Star-Triangle Transformation



Progress of Theoretical Physics, Vol. VI, No. 3, May~June, 1951.

Statistics of Kagomé Lattice

Itiro Syôzi

Department of Physics, Osaka University

(Received February 27, 1951)

The transition temperature of the kagomé lattice with $Z=4$ is obtained and compared with that of the square lattice.

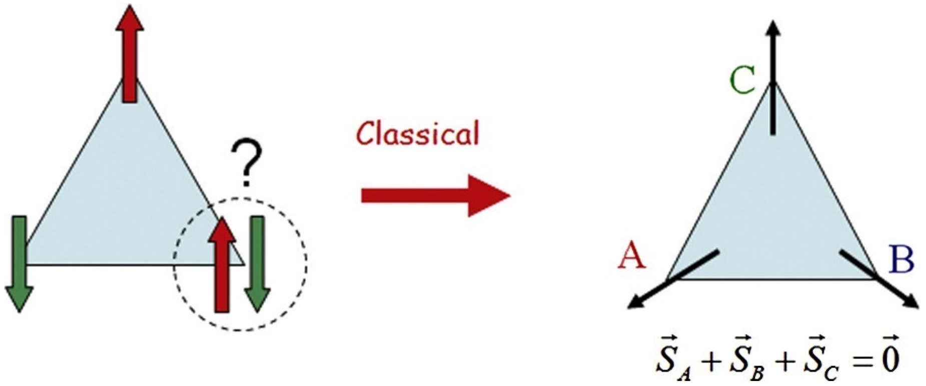
After the work of Onsager,[1] who solved exactly the problem of Ising model for the case of plane square lattice, the same problems for the honeycomb and triangular lattice were treated by several authors.[2] Other than these three types of lattices, there is left a lattice, called in Japanese kagomé (woven bomboo pattern), which consists exclusively of equivalent lattice points and equivalent bonds. Since the number of nearest neighbors of a lattice point is as many as in the square lattice, namely four, it is interesting to verify the natural conjecture that the curie point, in general, is determined solely by the relation $\mathrm{ch}2H=\sec\pi/Z$ established by Onsager for the three types of lattices.

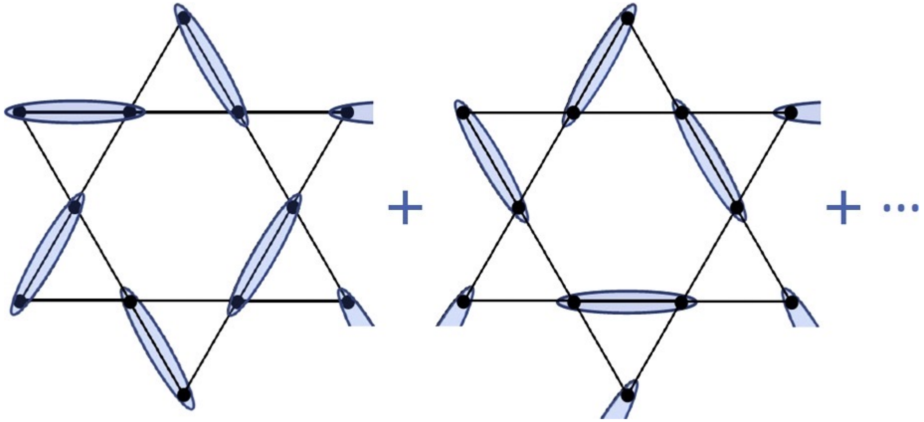
Fig. 1. Kagomé Lattice

Let us start from a variant of the honeycomb lattice, which has an extra spin on the middle point of every side as well as on every vertex (say decorated honeycomb lattice). Let its interaction parameter be L. By summing at first over the spin variables with respect to the vertices in the partition function of this lattice, we arrive at the partition function of the kagomé lattice (Star-triangle transformation), with an interaction parameter K; in fine

I. Syôzi, Prog. Theor. Phys. 6, 306 (1951).
Mamoru Mekata , "Kagome: The Story of the Basketweave Lattice", Physics Today 56, 12-13 (2003)

Frustration in Kagome Network



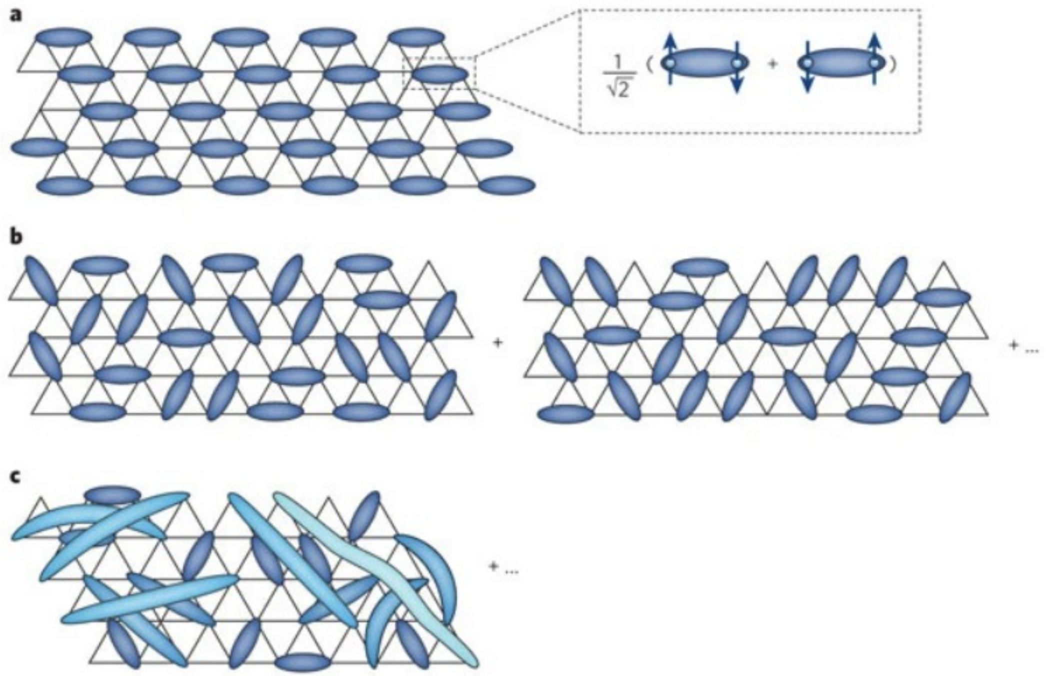


Mendels, P., & Bert, F. (2016). Comptes Rendus Physique, 17(3-4), 455-470.

Resonant Valence Bond Theory

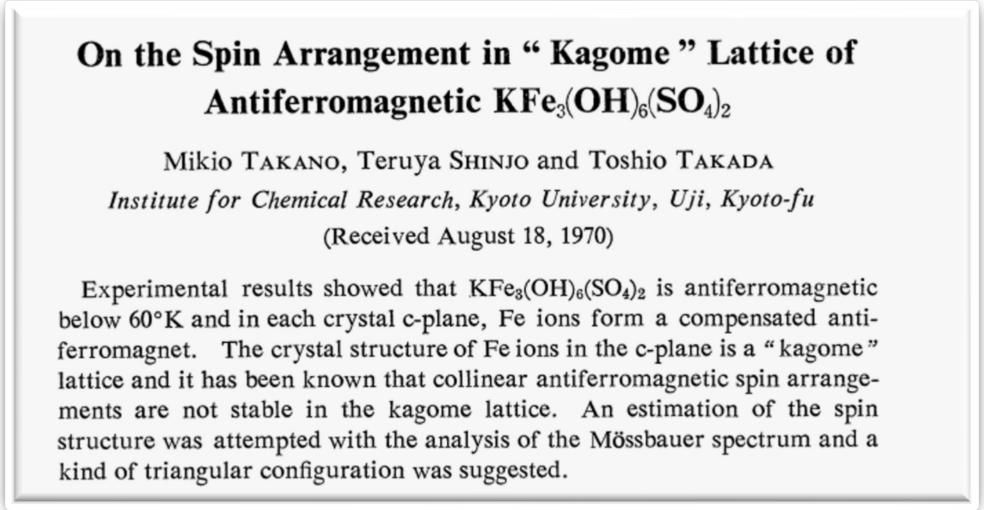
- Valence bonds are allowed to undergo quantum mechanical fluctuations
- GS is a superposition of different partitionings of spins into valence bonds

Figure 3: Valence-bond states of frustrated antiferromagnets.



Mendels, P., & Bert, F. (2016). Comptes Rendus Physique, 17(3-4), 455-470.

First Kagome Candidate



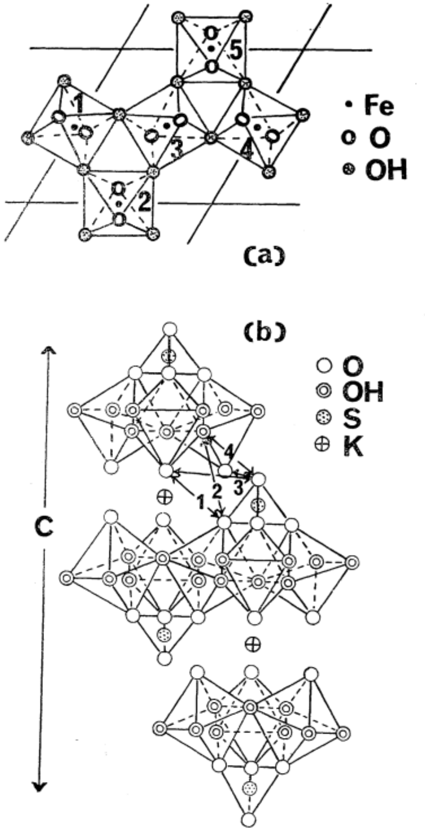
On the Spin Arrangement in “Kagome” Lattice of Antiferromagnetic $KFe_3(OH)_6(SO_4)_2$

Mikio Takano, Teruya Shinjo and Toshio Takada

Institute for Chemical Research, Kyoto University, Uji, Kyoto-fu

(Received August 18, 1970)

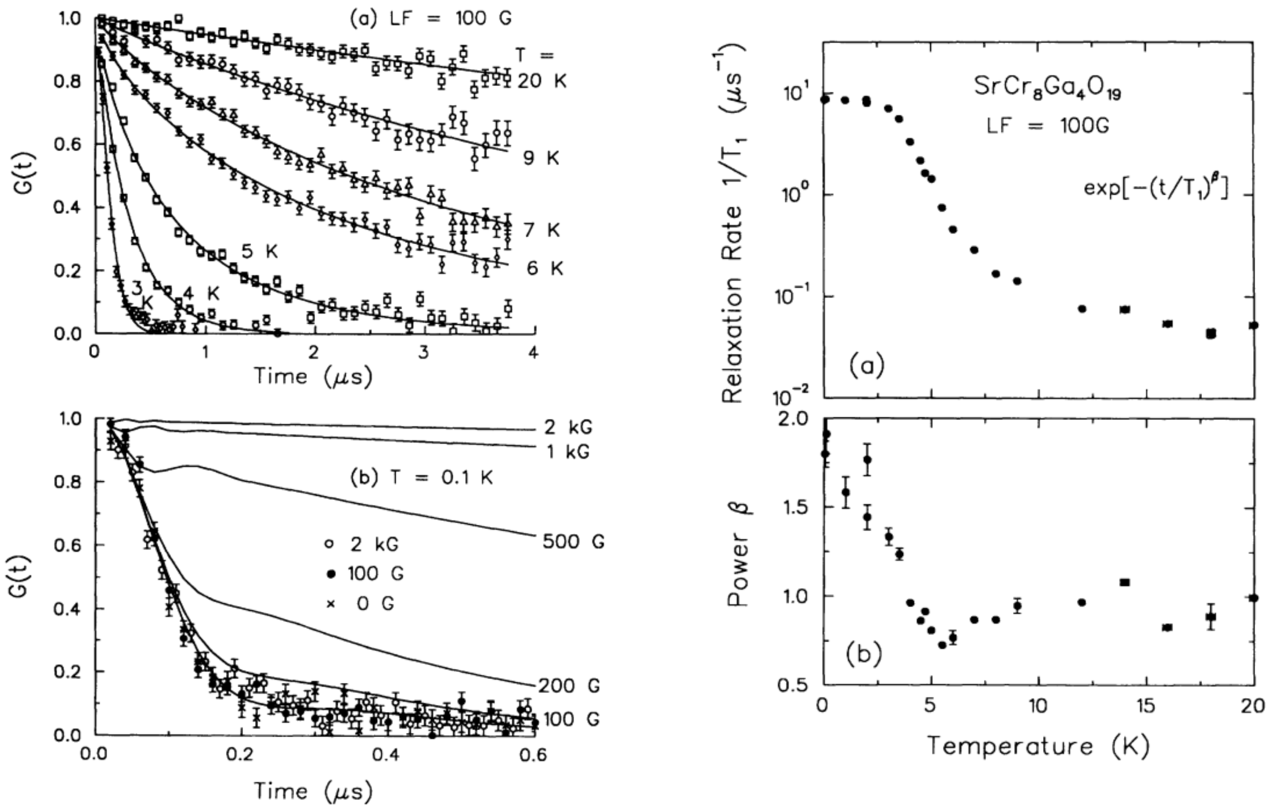
Experimental results showed that $KFe_3(OH)_6(SO_4)_2$ is antiferromagnetic below 60°K and in each crystal c-plane, Fe ions form a compensated antiferromagnet. The crystal structure of Fe ions in the c-plane is a “kagome” lattice and it has been known that collinear antiferromagnetic spin arrangements are not stable in the kagome lattice. An estimation of the spin structure was attempted with the analysis of the Mössbauer spectrum and a kind of triangular configuration was suggested.



Jarosite

M. Takano, T. Shinjo, M. Kiyama, T. Takada, J. Phys. Soc. Jpn. 25, 902 (1968)
https://underthescopemineral.tumblr.com/post/178252086249/jarosite-kfe3-3so42oh6-localityla

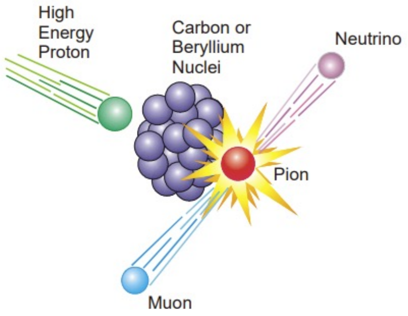
Kagome System $SrCr_8Ga_4O_{19}$

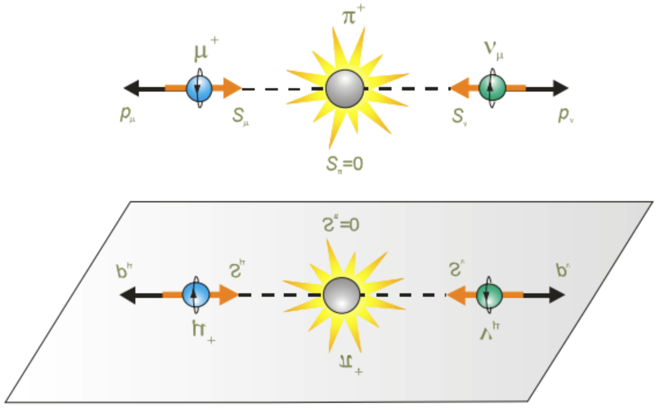


Uemura, Y. J., Keren, A., Kojima, K., Le, L. P., Luke, G. M., Wu, W. D., ... & Kakurai, K. Phys Rev Lett. 73(24), 3306. (1994)

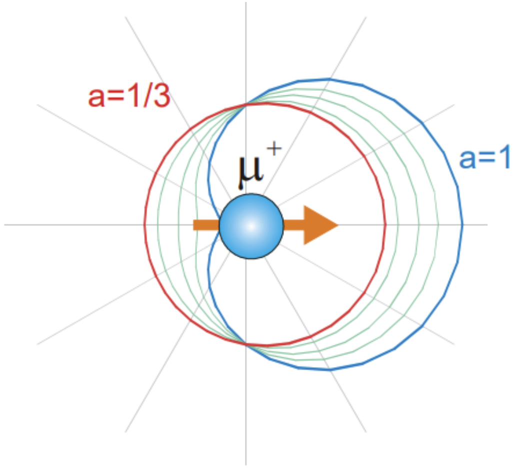
$$\pi^{+} \rightarrow \mu^{+} + \nu_{u}$$
$$\pi^{-} \rightarrow \mu^{-} + \overline{\nu}_{\mu}$$

μSR Muon Spin Relaxation Technique





Parity-violating collinear decay of a pion π^{+} at rest into a muon μ^{+} and a muonic neutrino ν_{μ}.

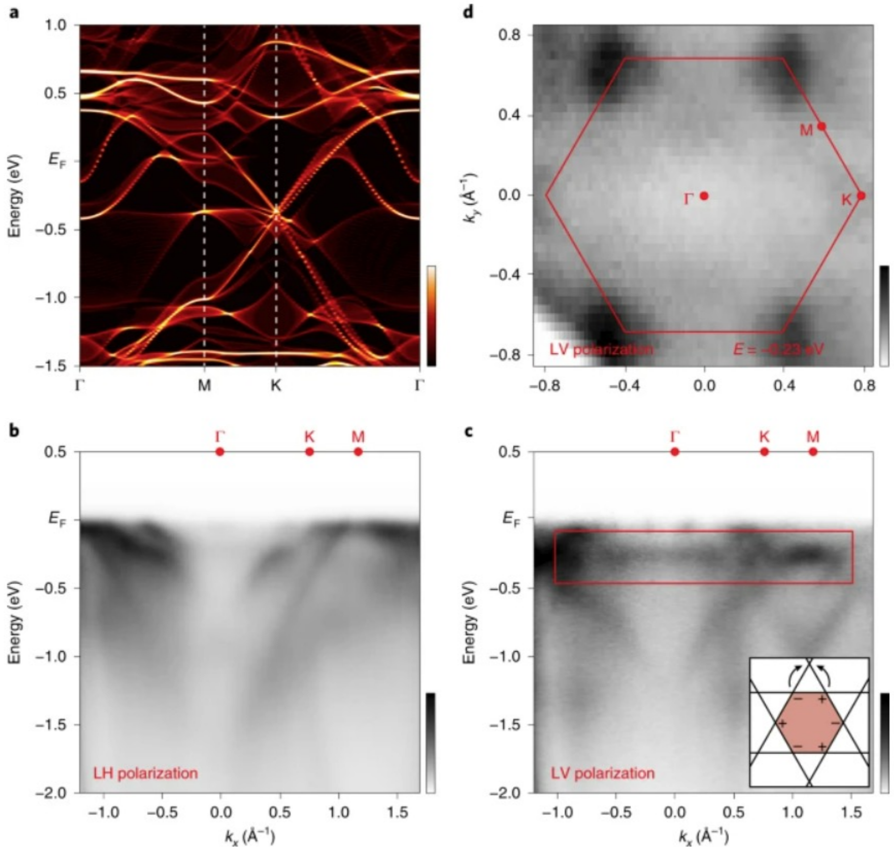


Angular distribution of the positrons from the muon decay: $W(E,\theta) = 1 + a(E)\cos(\theta)$. When all positron energies E are sampled with equal probability the asymmetry parameter has the

http://www.chem.ubc.ca/sites/default/files/users/dgf/musrbrochure.pdf

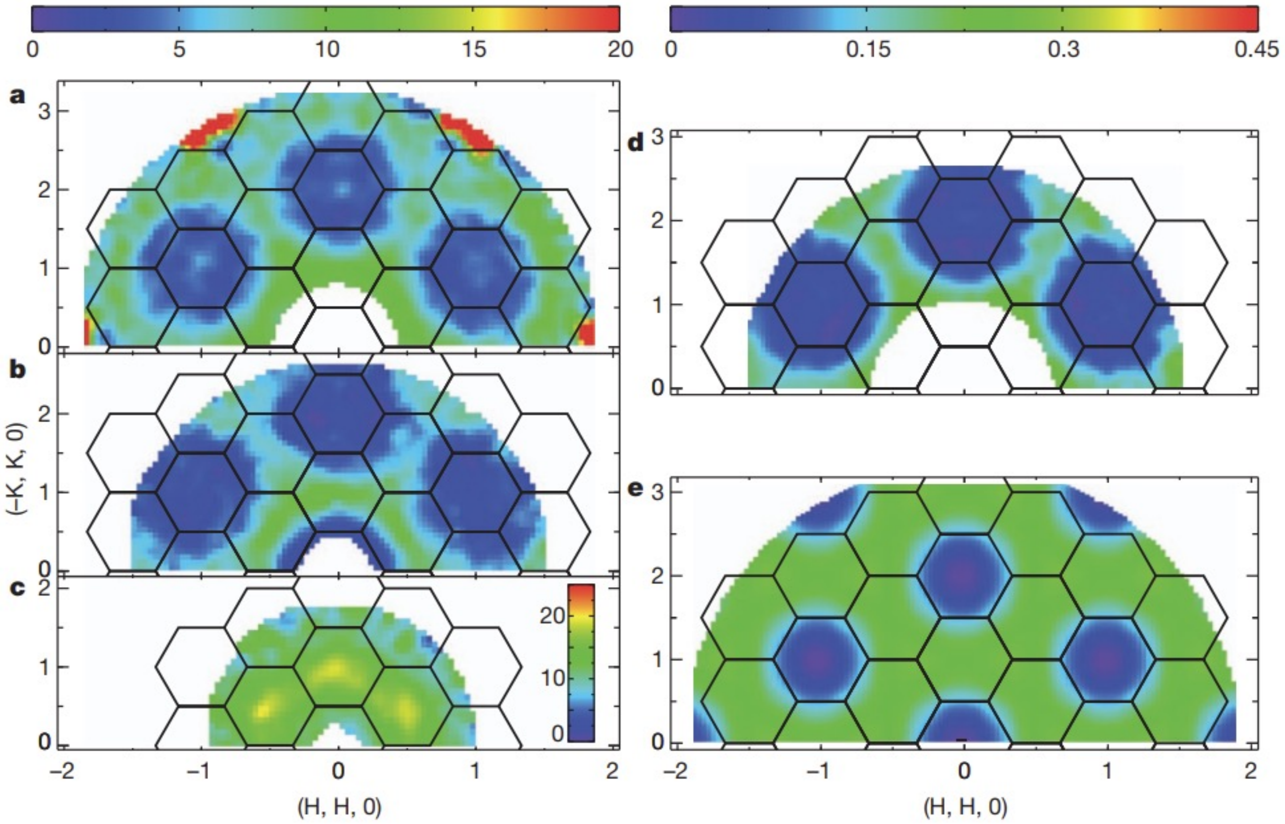
Kagome FeSn

Fig. 4: Signature of flat bands in FeSn.



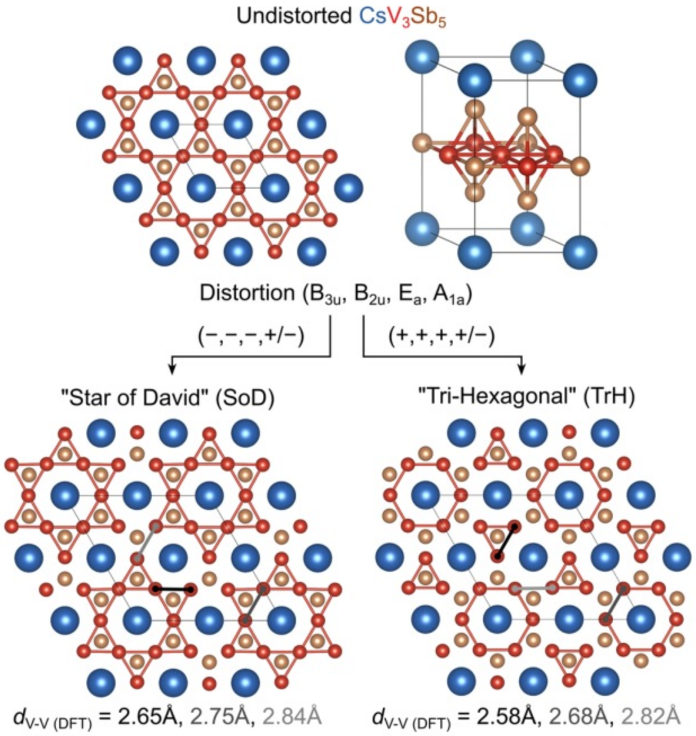
Kang, M., Ye, L., Fang, S. et al. Dirac fermions and flat bands in the ideal kagome metal FeSn. Nat. Mater. 19, 163–169 (2020).

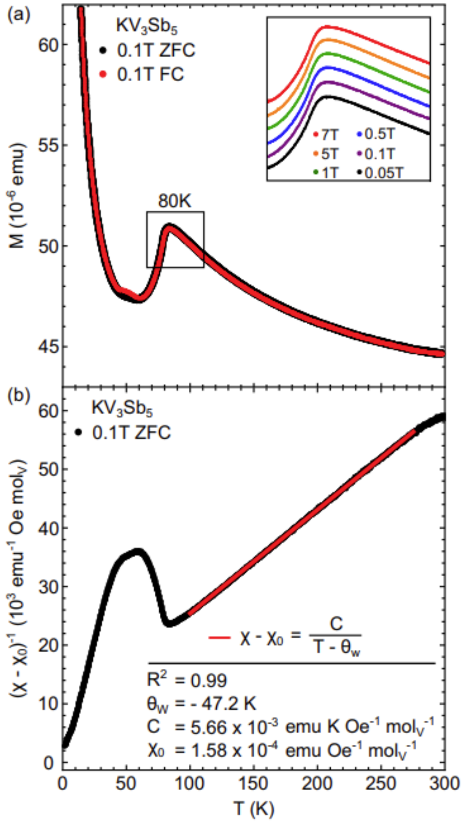
$ZnCu_3(OD)_6Cl_2$ (herbertsmithite)



Han, T. H., Helton, J. S., Chu, S., Nocera, D. G., Rodriguez-Rivera, J. A., Broholm, C., & Lee, Y. S. (2012). Fractionalized excitations in the spin-liquid state of a kagome-lattice antiferromagnet. Nature, 492(7429), 406–410.

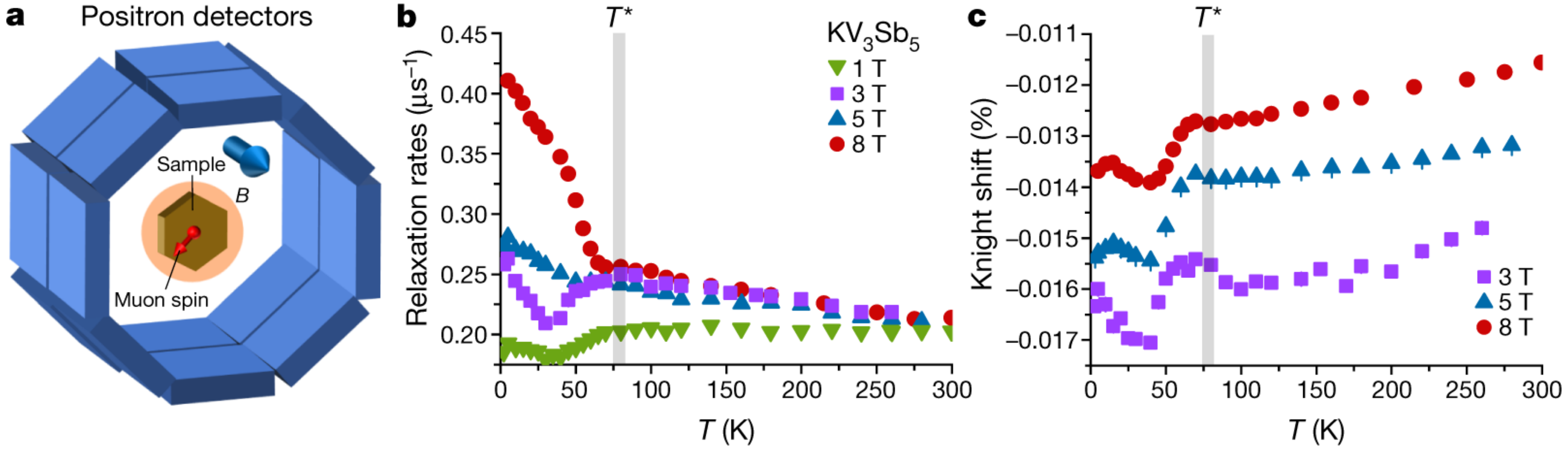
AV_3Sb_5 (A=K,Rb,Cs)





Ortiz, B. R; Teicher, S.; Kautzsch, L.; Sarte, P. M; Ratcliff, N.; Harter, J., et al. Physical Review X, 11(4). (2021).
Ortiz, Brenden R., Gomes, Lídia C., Morey, Jennifer R., Winiarski, Michal, Bordelon, Mitchell, Mangum, John S., Oswald, Iain W. H., Rodriguez-Rivera, Jose A., Neilson, James R., Wilson, Stephen D., Ertekin, Elif, McQueen, Tyrel M., & Toberer, Eric S. (2019)

AV_3Sb_5 (A=K,Rb,Cs)



Mielke, C., Das, D., Yin, JX. et al. Time-reversal symmetry-breaking charge order in a kagome superconductor. Nature 602, 245–250 (2022).

Thank You!