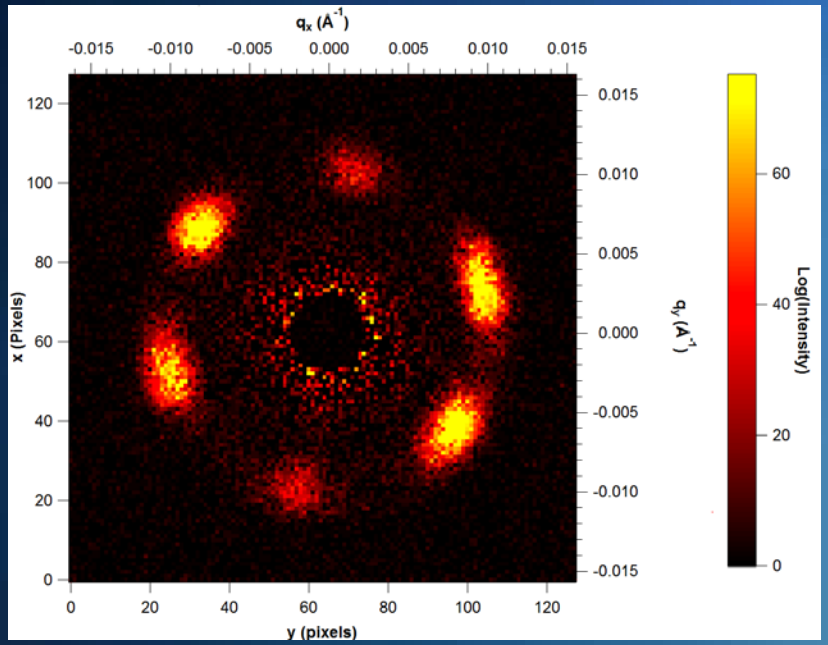
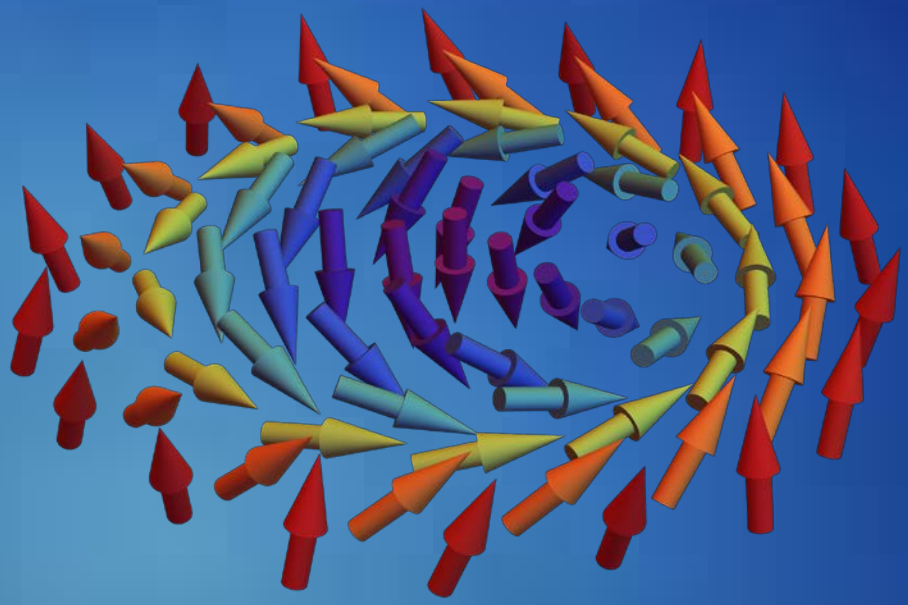




All Tied Up in Knots: Skyrmions in Chemically Substituted Cu_2OSeO_3

Presenter: Paul Neves

Mentors: Nicholas Butch & Juscelino Leão

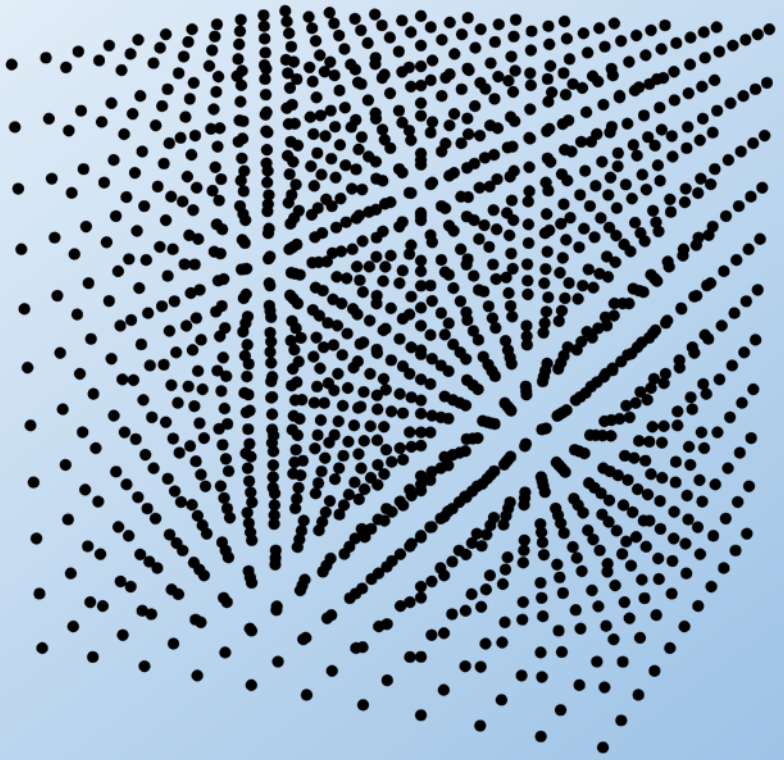
NIST Center for Neutron Research

Summer Undergraduate Research Fellowship

Our Project Goal

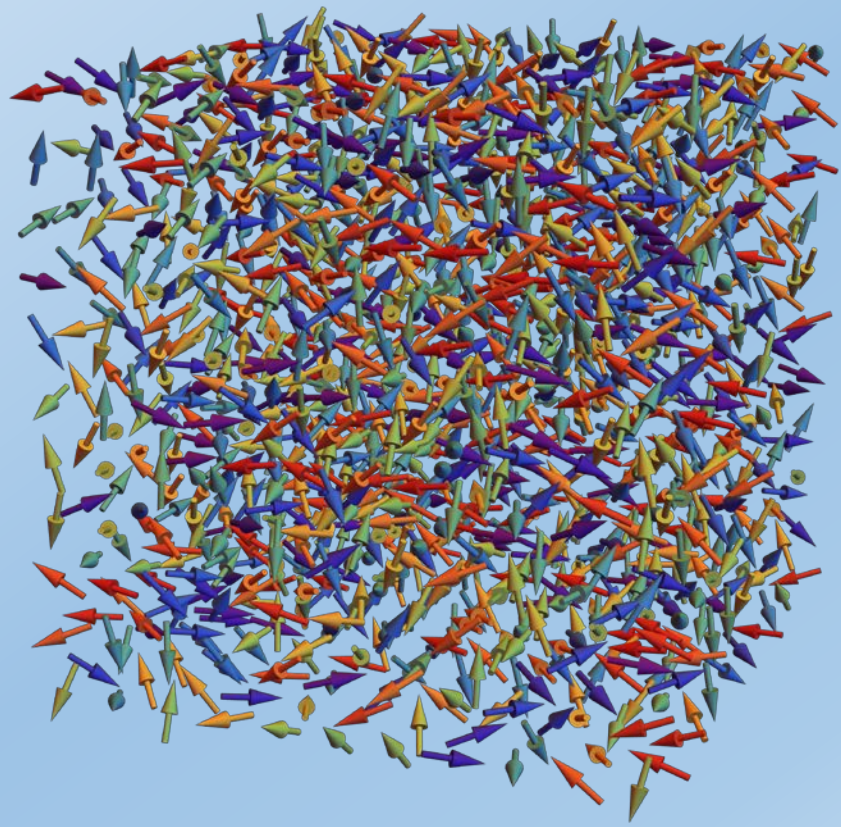
- **What:** Can we understand the effects of chemical substitution on the stability of magnetic skyrmions?
- **Why:** Can we control/tune the skyrmion phase?
  - Normally small stability window

Magnetic Structures



Nonmagnetic

Atomic Lattice

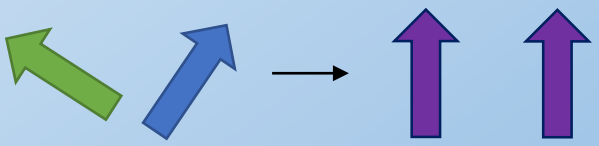


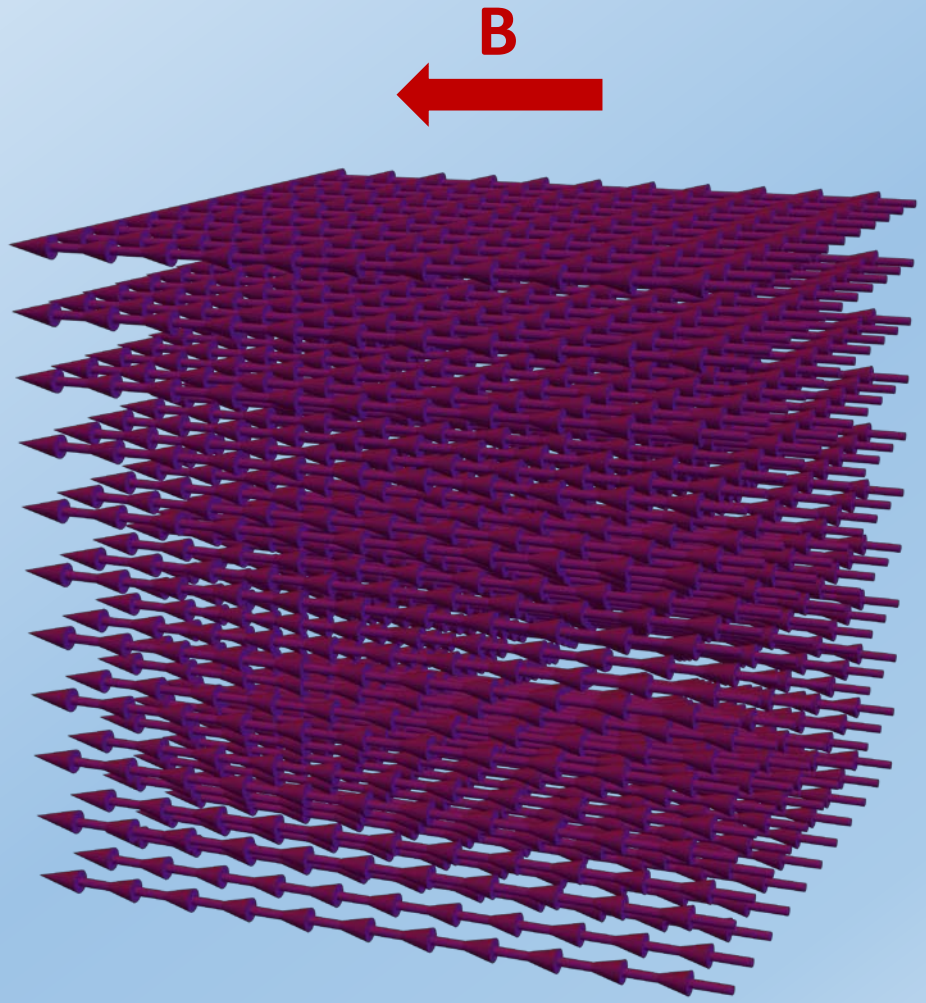
Para/diamagnetic

Atomic Lattice

Magnetic Structures

- What happens when we add interactions between the spins?
  - Ferromagnetism, for example
- Can we have other structures?

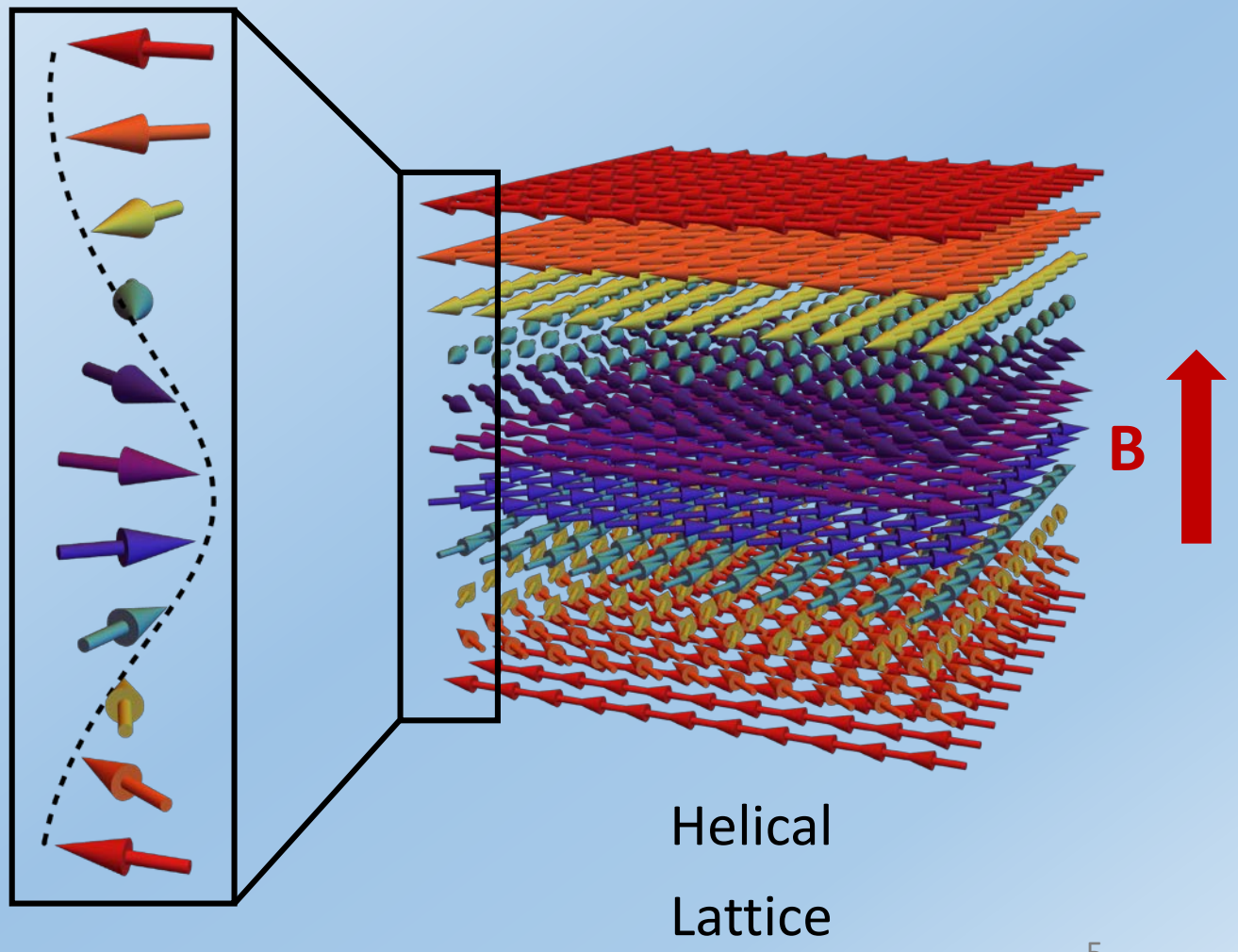




Ferromagnetic Lattice

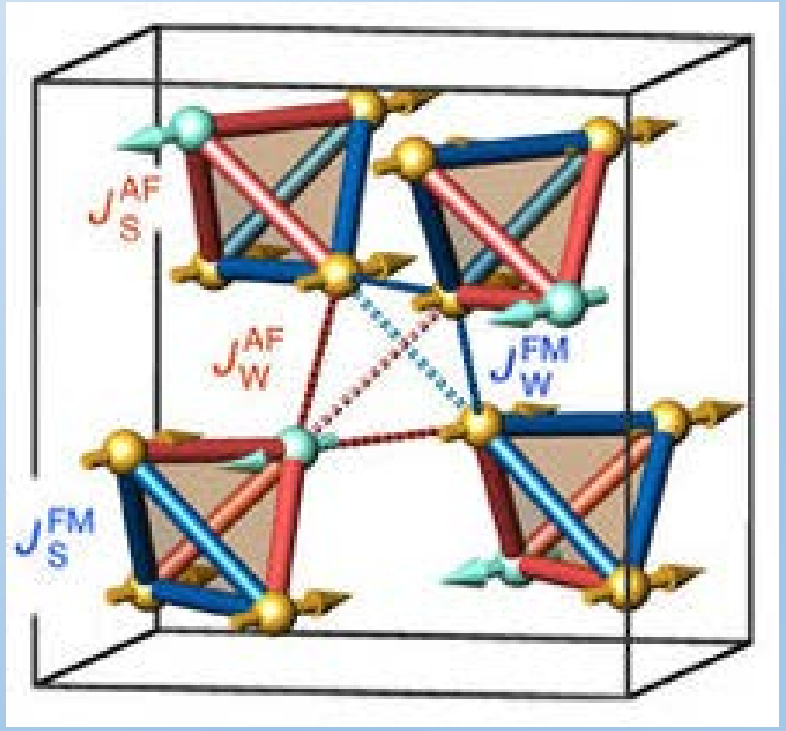
Magnetic Structures

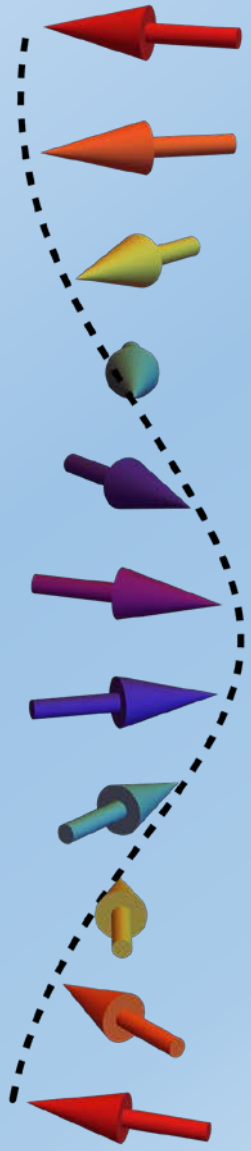
- More complex interactions can lead to helical structures



An Interesting Material: Cu_2OSeO_3

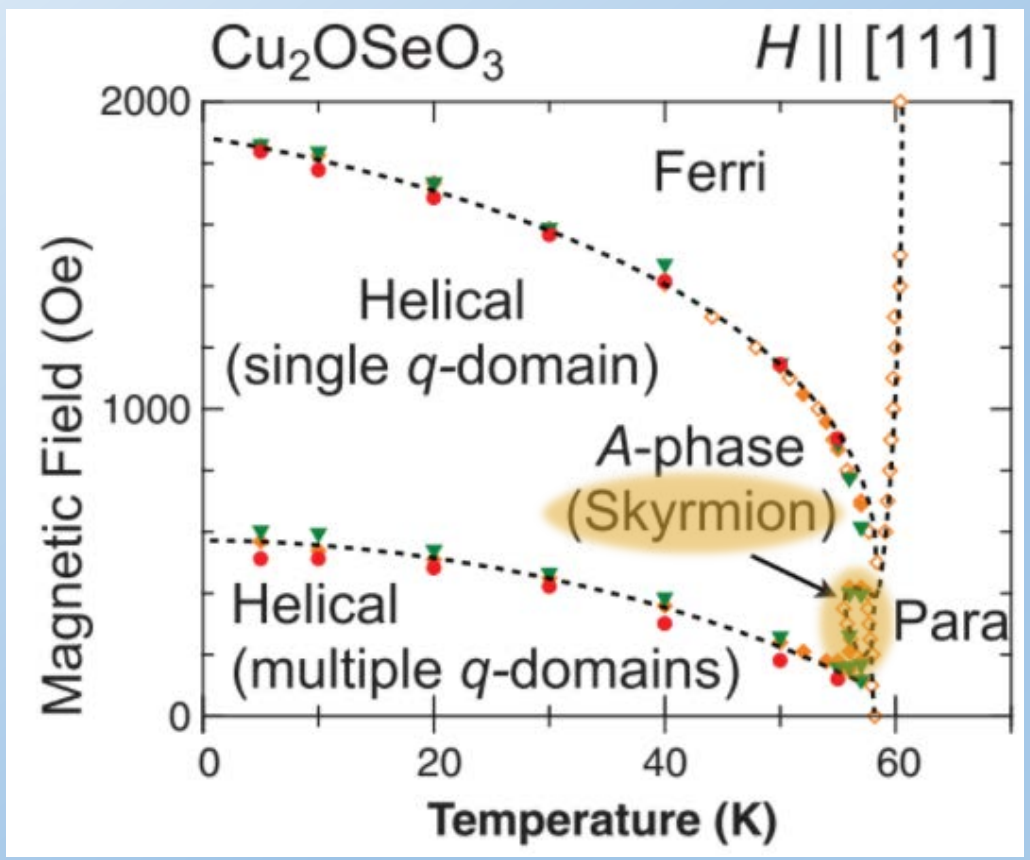
- Insulating
- Magnetically interacting Cu sites
- Helimagnetic





Janson, O. *et al.* The quantum nature of skyrmions and half-skyrmions in Cu_2OSeO_3. *Nature Communications* 5, (2014)

An Interesting Material: Cu_2OSeO_3

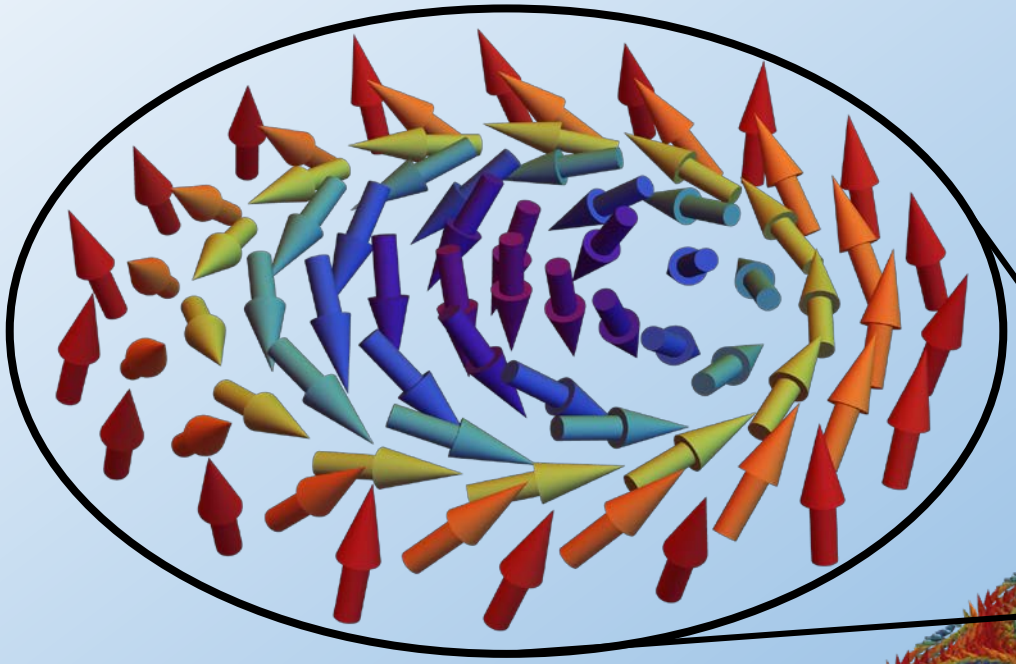


(10 Oe = 1 mT)

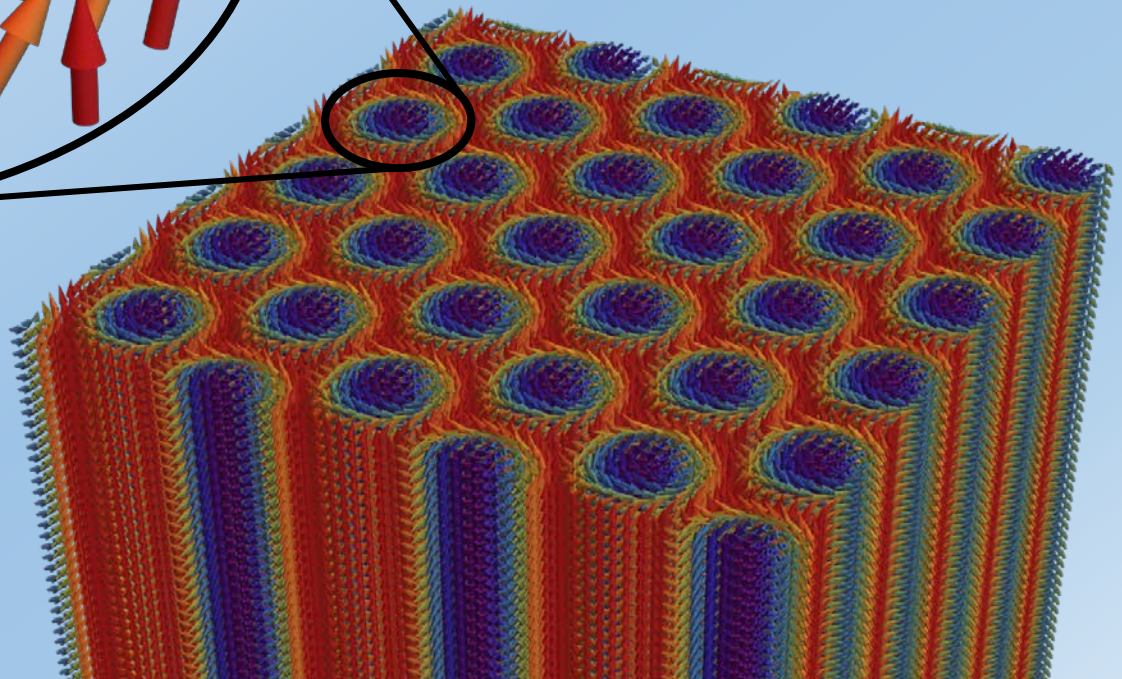
Seki, S. *et al.* Observation of Skyrmions in a Multiferroic Material. *Science* **336,** 198-201 (2012)

Magnetic Skyrmions

- Topologically protected
  - <>MNSJKAGHICGSA
  - Robust (stable)
  - Potential data storage applications



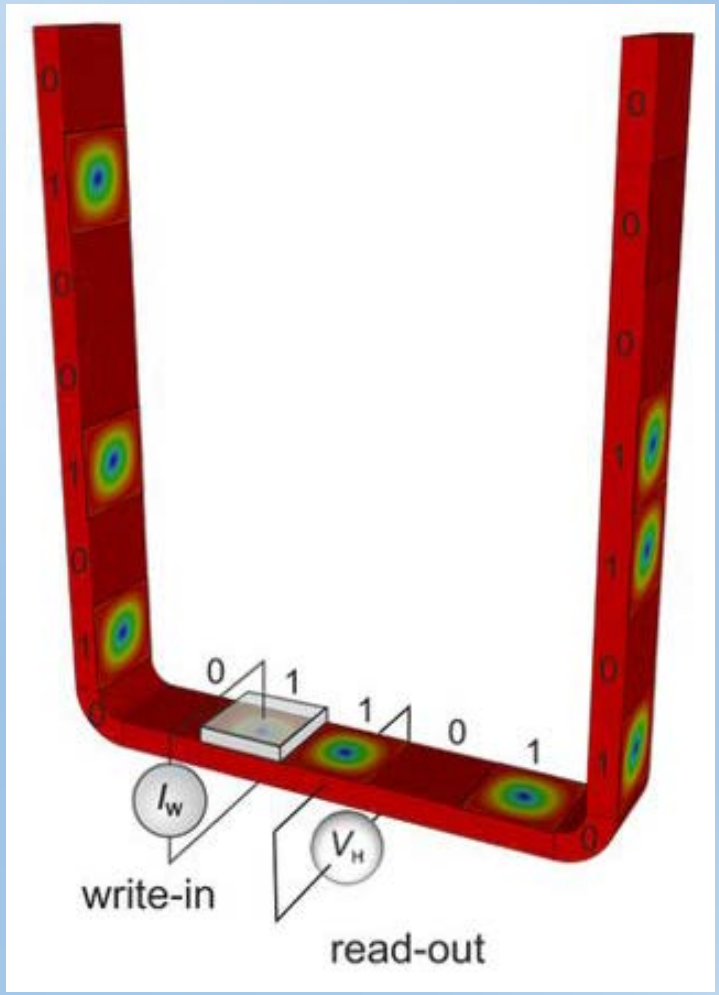
(10 – 100 nm size)



CHRNS

Possible Data Storage Applications

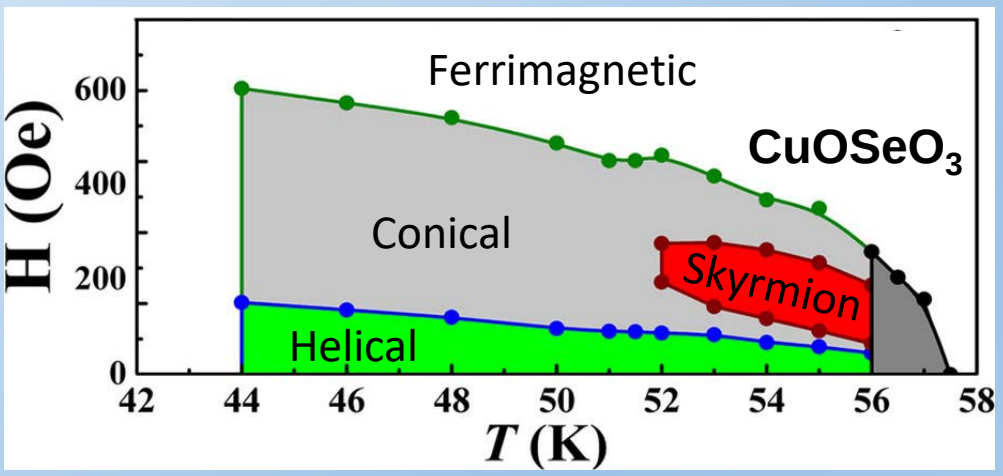
- Protected data storage
  - Topological
- Spintronics
  - Not just 1's and 0's
- High density data storage
  - Nanoscale

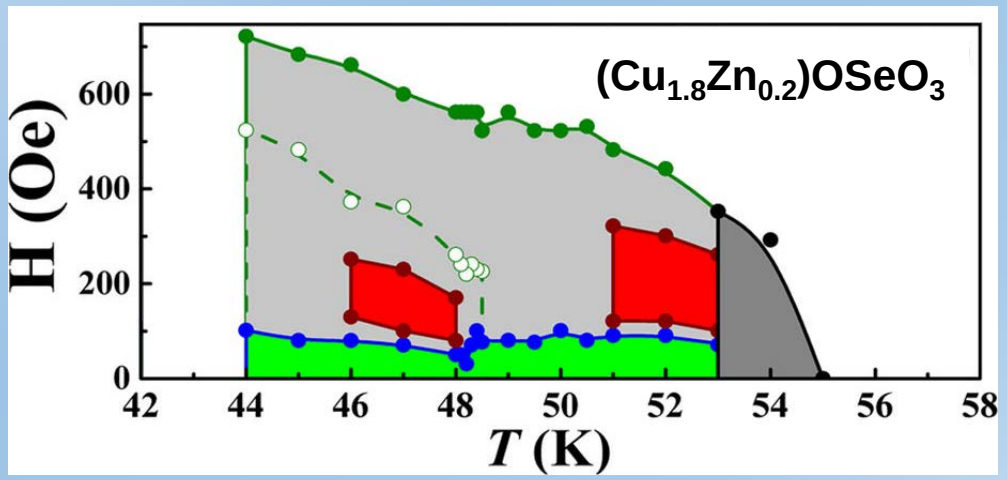


Zhang, Shilei, et al. "Topological computation based on direct magnetic logic communication." *Scientific reports* 5 (2015): 15773.

What is our Goal?

- Control/tune the phase
  - Small stability window
  - Chemical substitution affects the skyrmion phase
- Ex) Substitute Zn for Cu
  - Splits skyrmion phase?
  - Magnetization only
  - Structure not directly confirmed



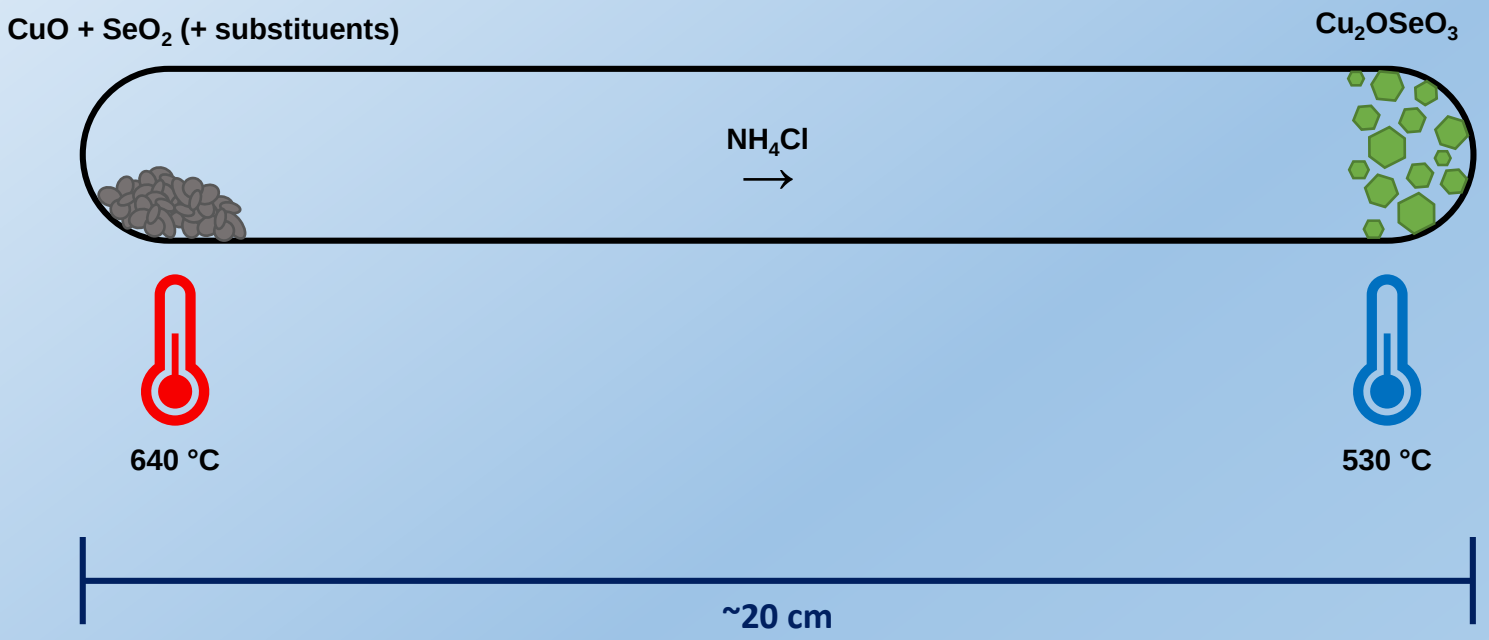


(10 Oe = 1 mT)

Wu, H. C. *et al.* Unexpected Observation of Splitting of Skyrmion Phase in Zn Doped Cu_2OSeO_3. *Science Reports* **5,** (2015)

How to Grow Single Crystals

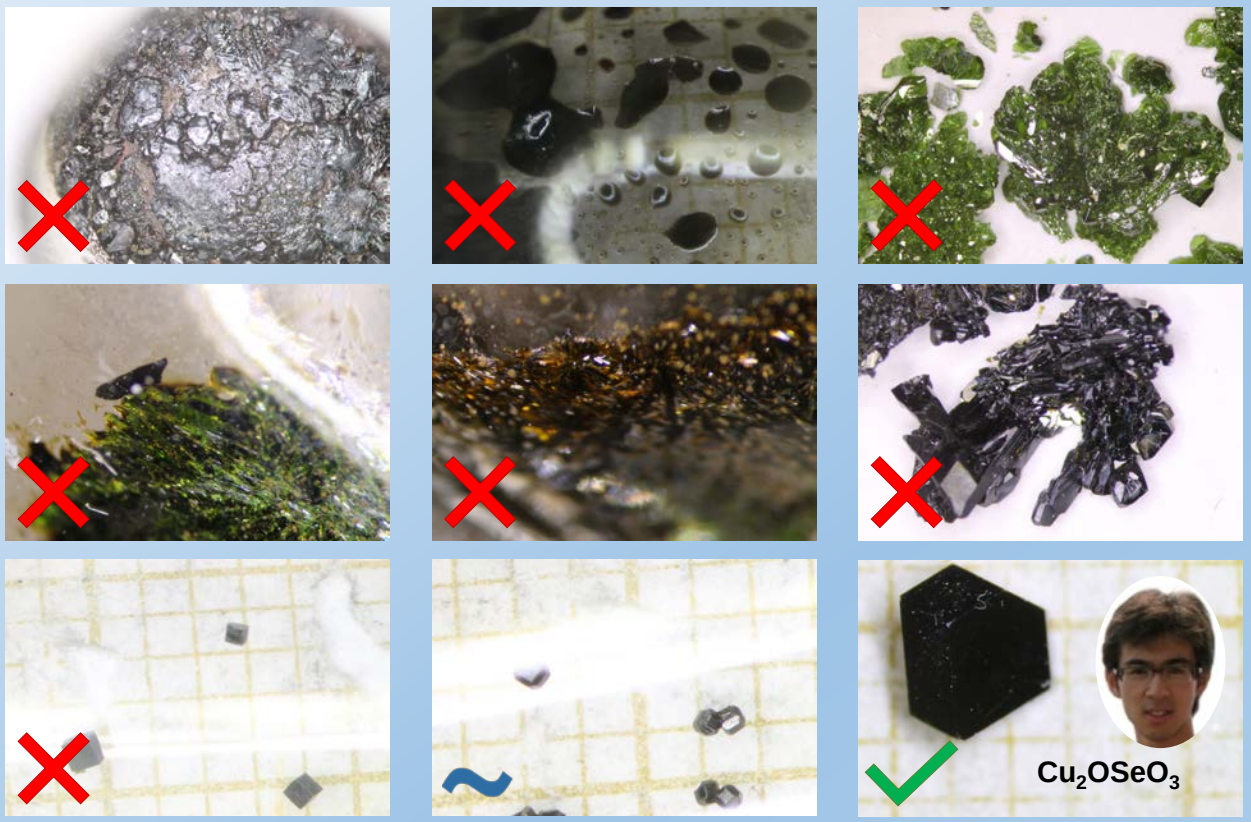
- Chemical vapor deposition
  - Manipulates chemical equilibrium with temperature



Panella, Jessica R., et al. "Seeded chemical vapor transport growth of Cu2OSeO3." *Crystal Growth & Design* 17.9 (2017): 4944-4948.

How *not* to Grow Single Crystals

- Chemical vapor deposition
  - Very sensitive to temperatures and pressure
  - Limited by chemistry



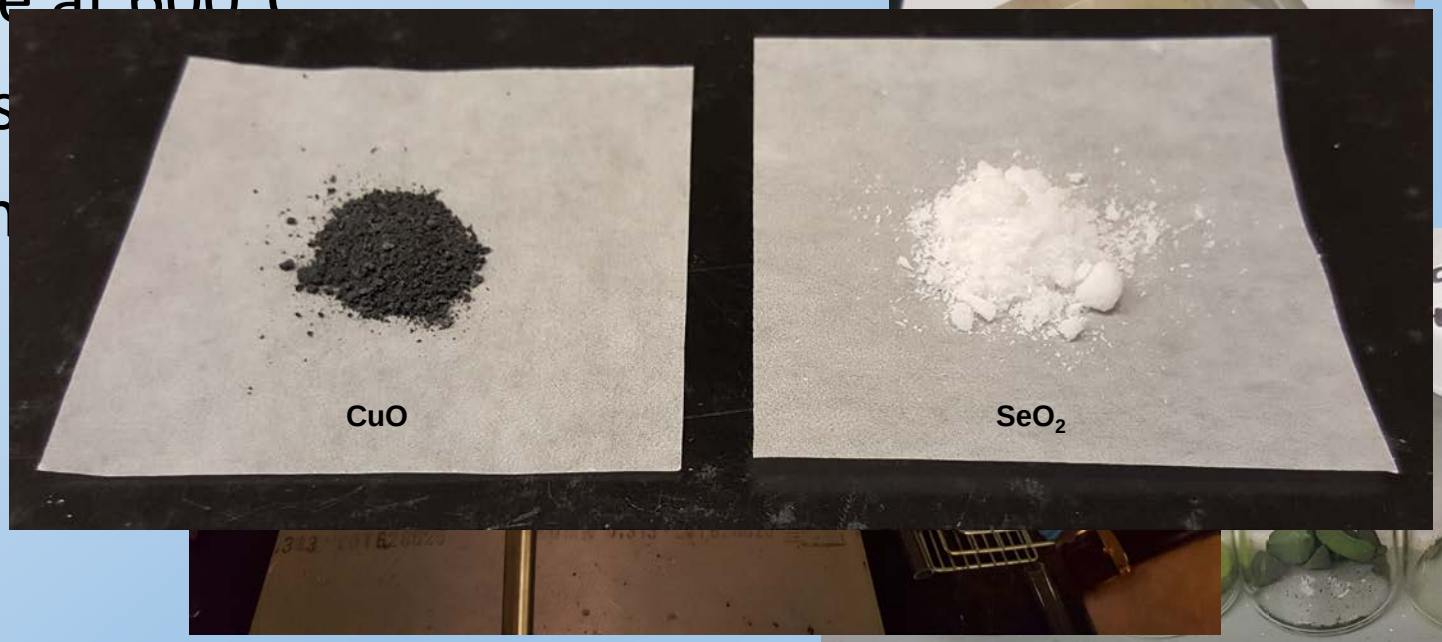
$(Cu_{1.8}Zn_{0.2})OSeO_3$?

Se	Zn	Cu	O
0.95375	0.00267	2.09	4

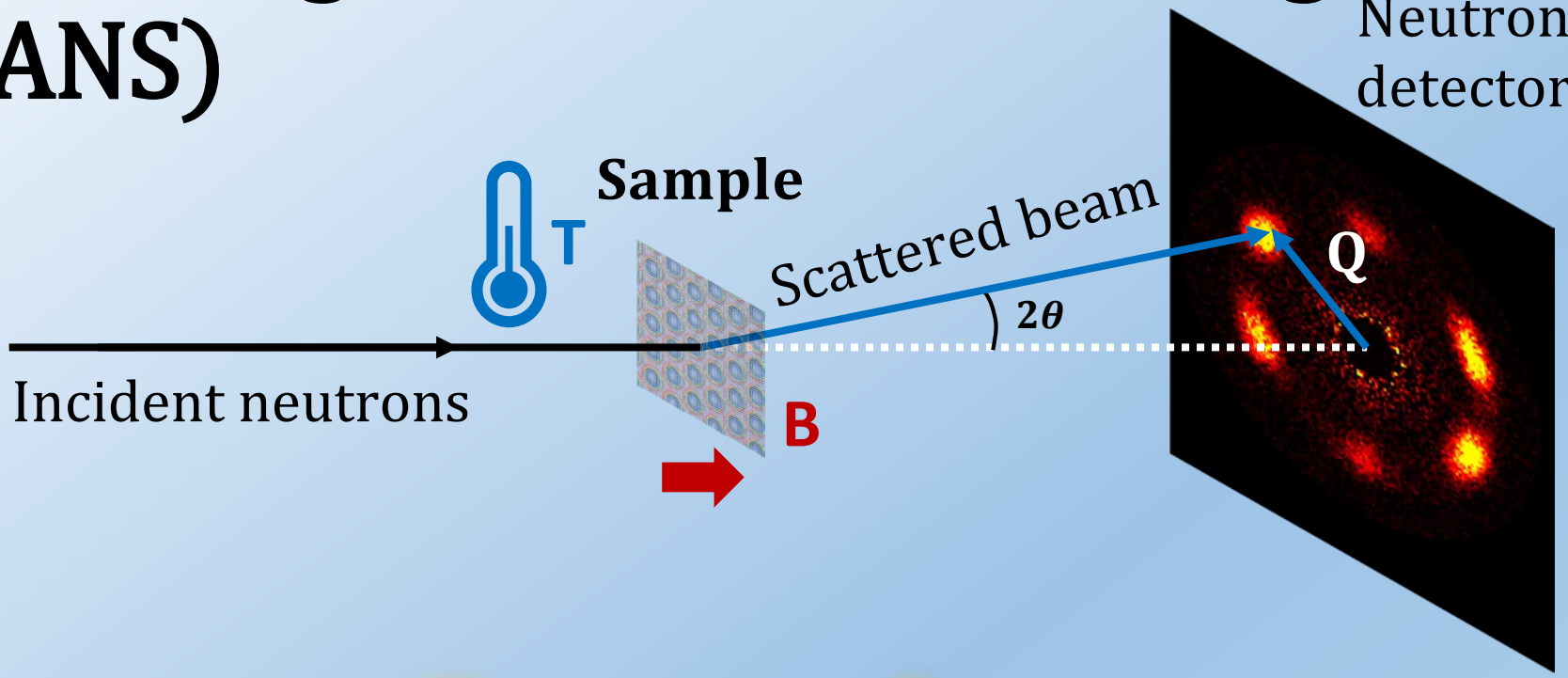
!

Making Polycrystals

- Mix/grind CuO and SeO_2
  - (and any substitutions)
- Seal in evacuated quartz tube
- Bake at 600°C
- Pres
- Lath

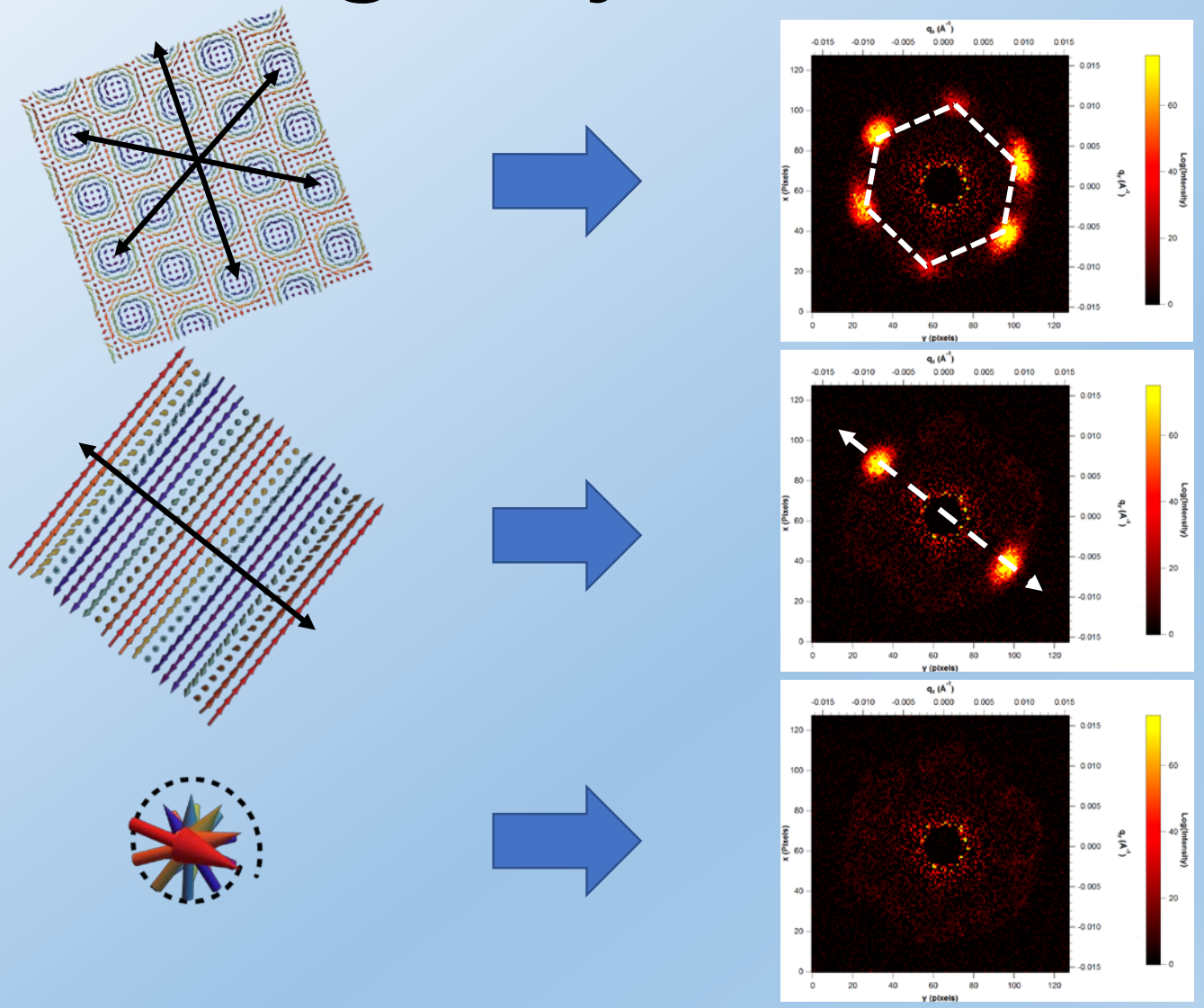


Small Angle Neutron Scattering (SANS)



$$Q = \frac{2\pi}{d} = \frac{4\pi}{n\lambda}\sin\theta$$

SANS in a Single Crystal

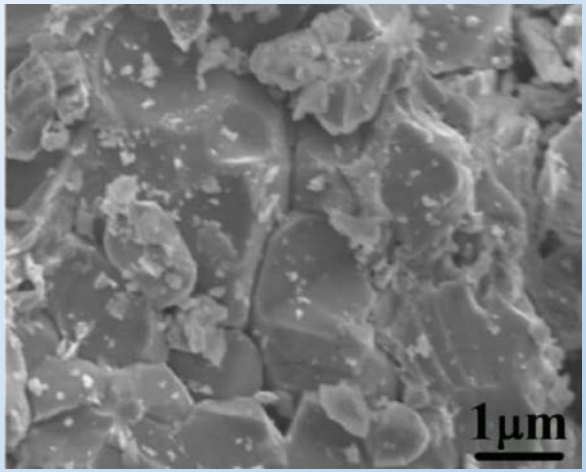


Real Space

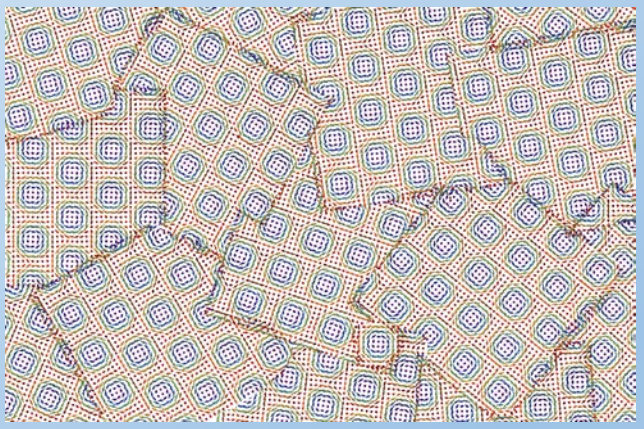
SANS

Skyrmions in SANS in a Powder

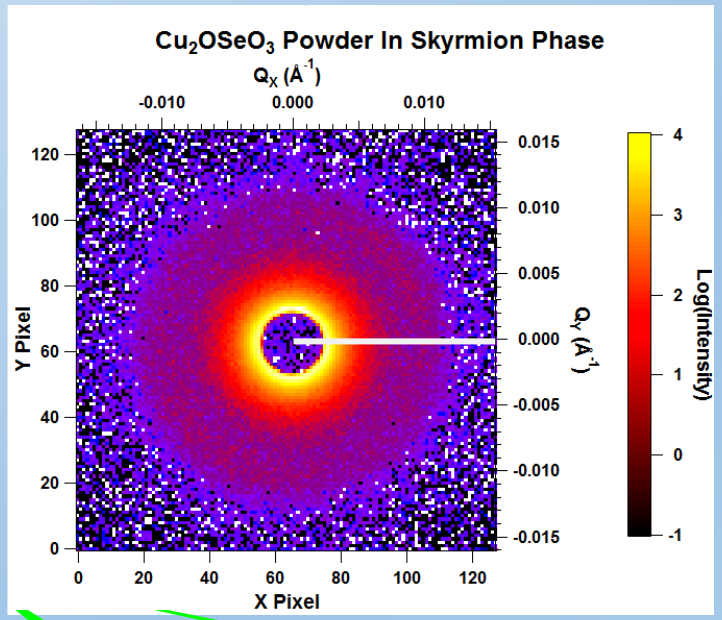
Real Space

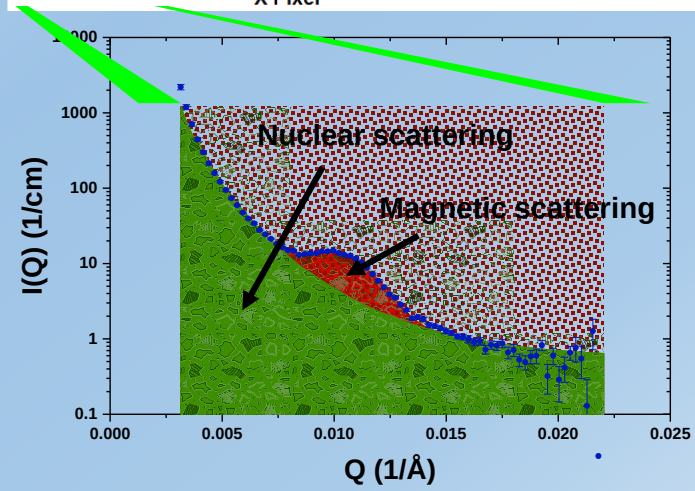


Wu, H. C. *et al.*

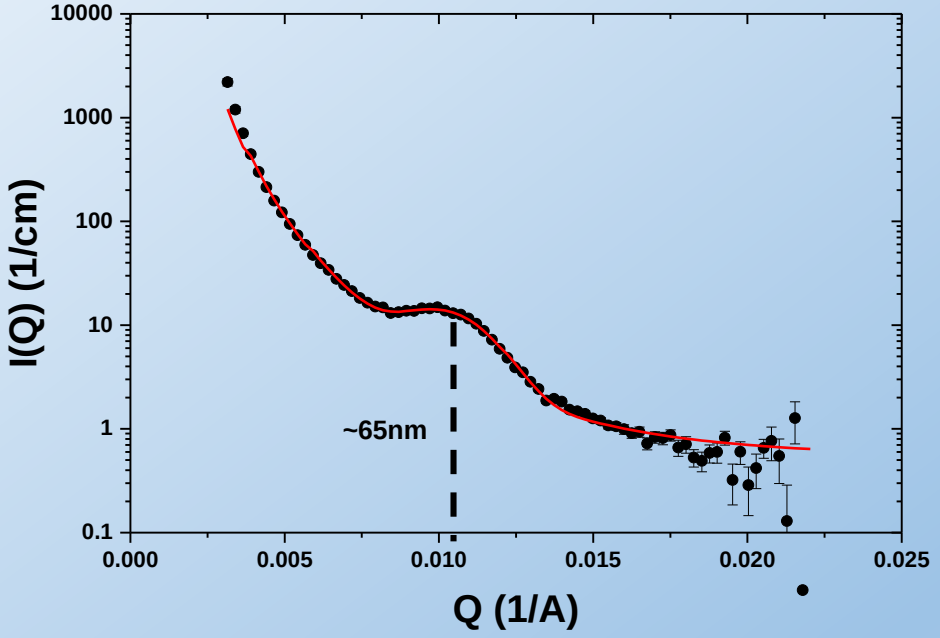


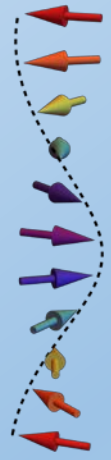
SANS



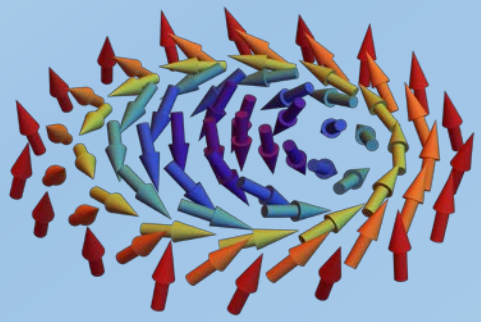


Skyrmions in SANS in a Powders



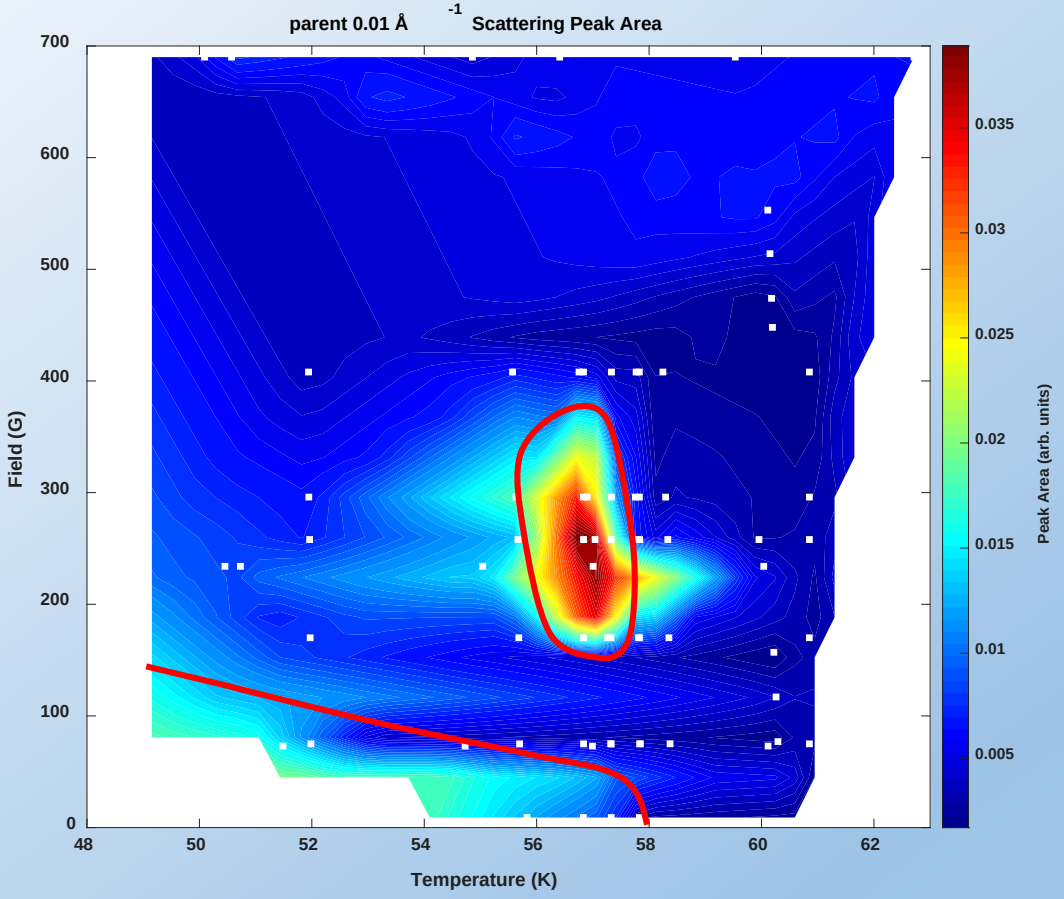


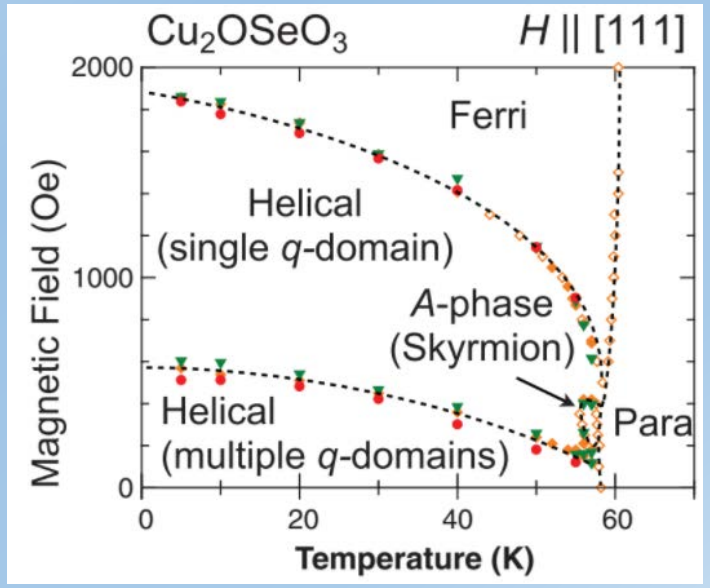
?



?

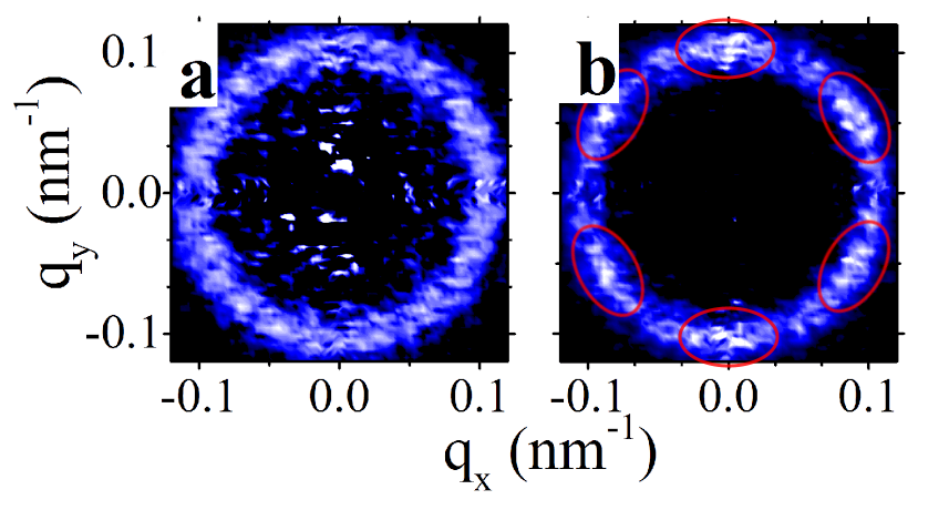
SANS: Cu_2OSeO_3 Powder

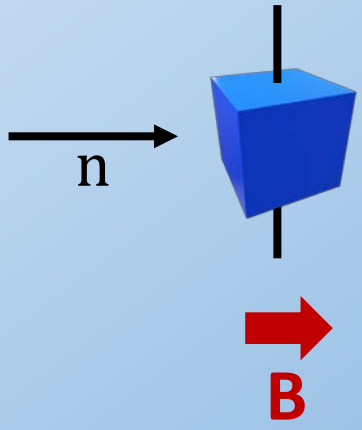


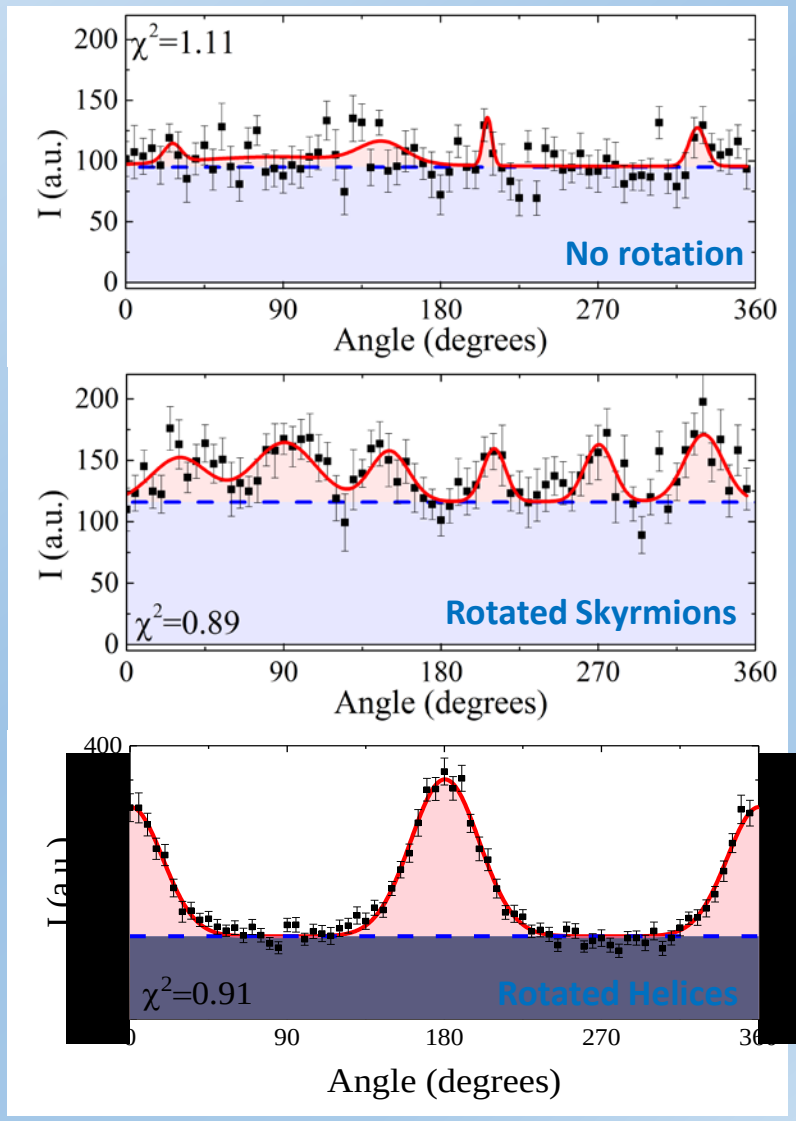


Seki, S. *et al.* Observation of Skyrmions in a Multiferroic Material. *Science* **336,** 198-201 (2012)

SANS: Rotation Technique



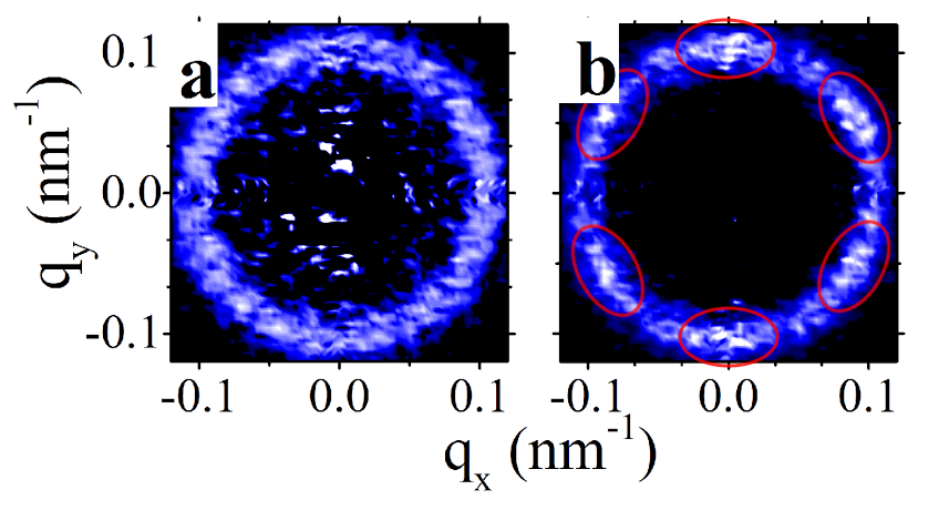


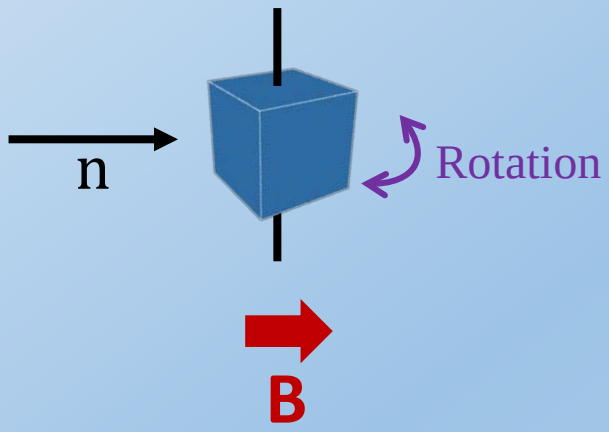


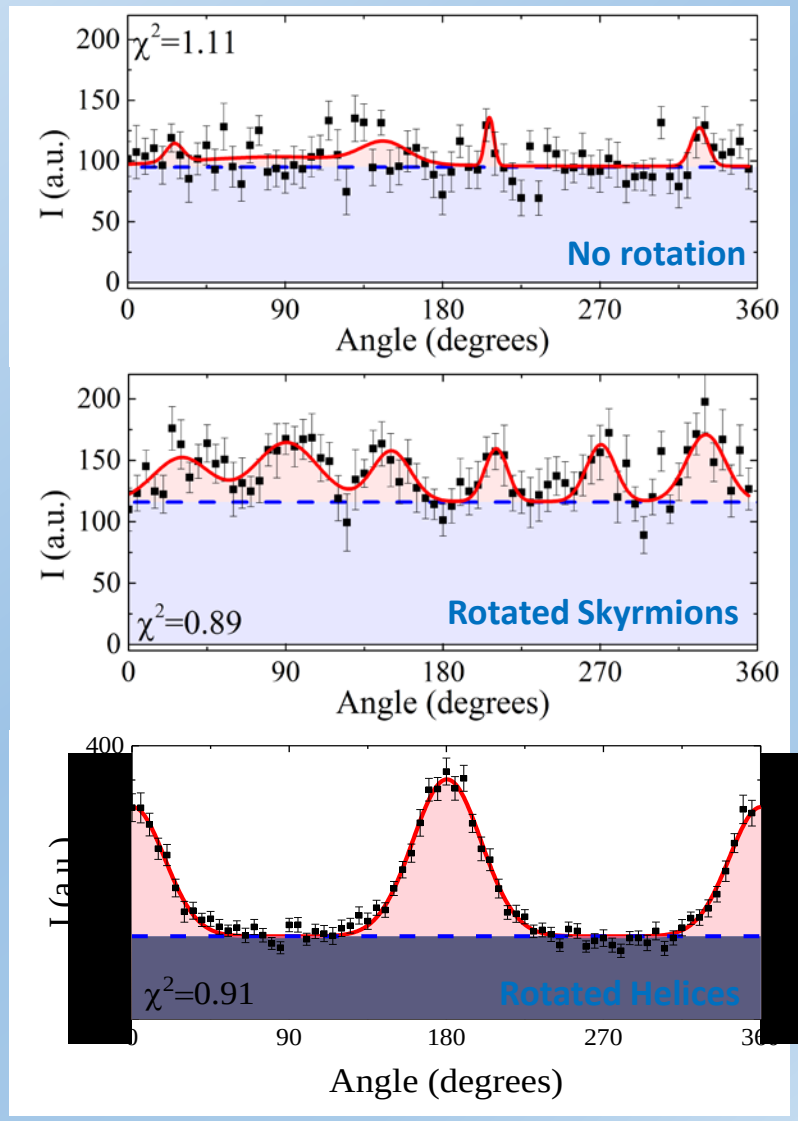
Dustin Gilbert

Precipitating Ordered Skyrmion Lattices from Helical Spaghetti

SANS: Rotation Technique



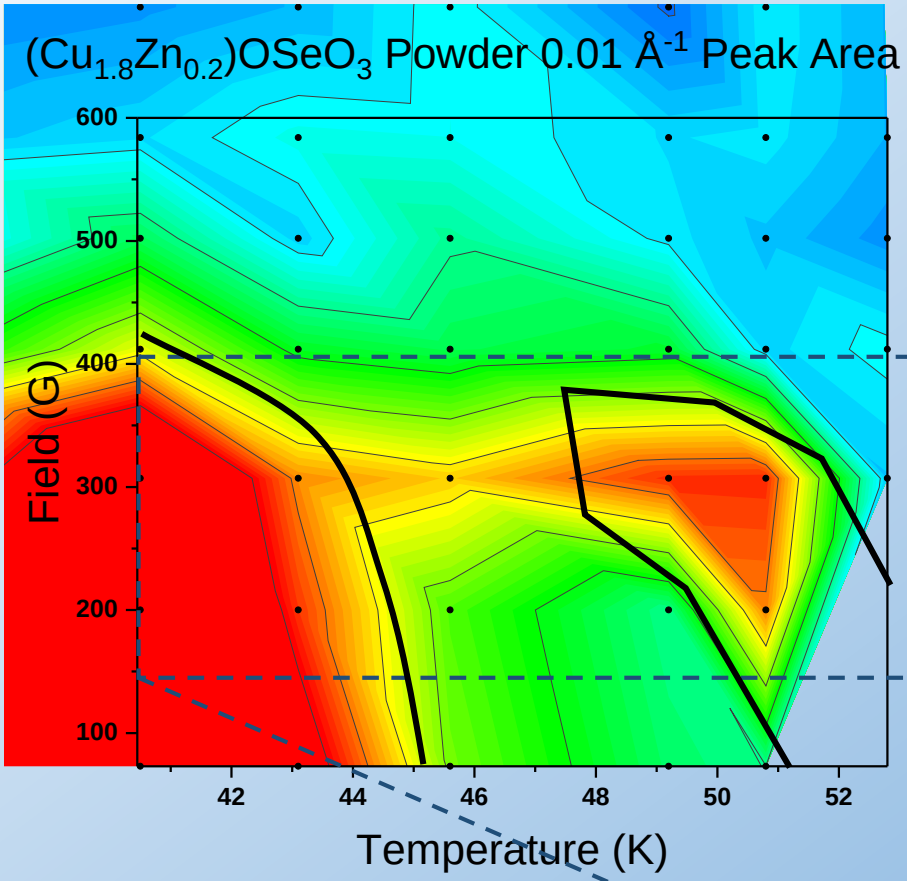


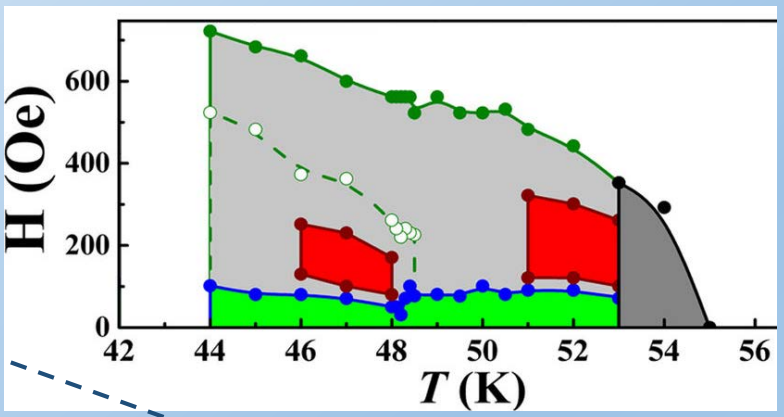


Dustin Gilbert

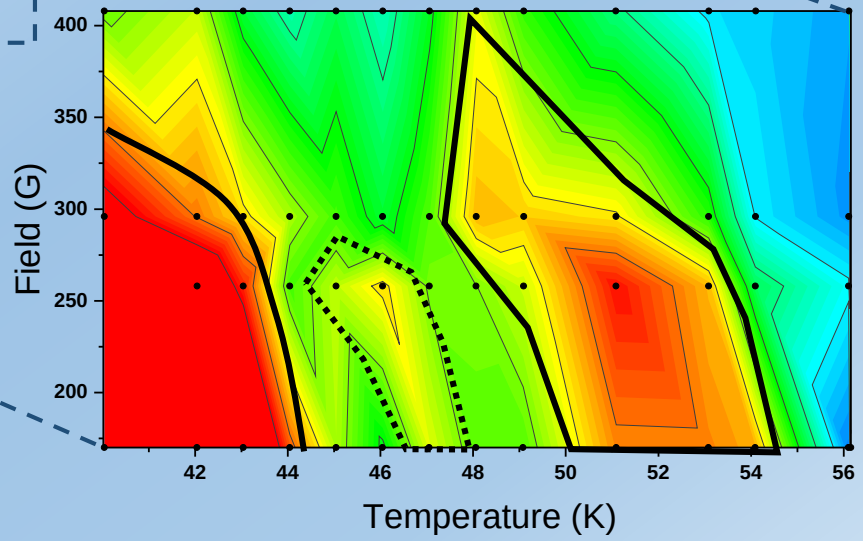
Precipitating Ordered Skyrmion Lattices from Helical Spaghetti

SANS: $(Cu_{1.8}Zn_{0.2})OSeO_3$ Powder



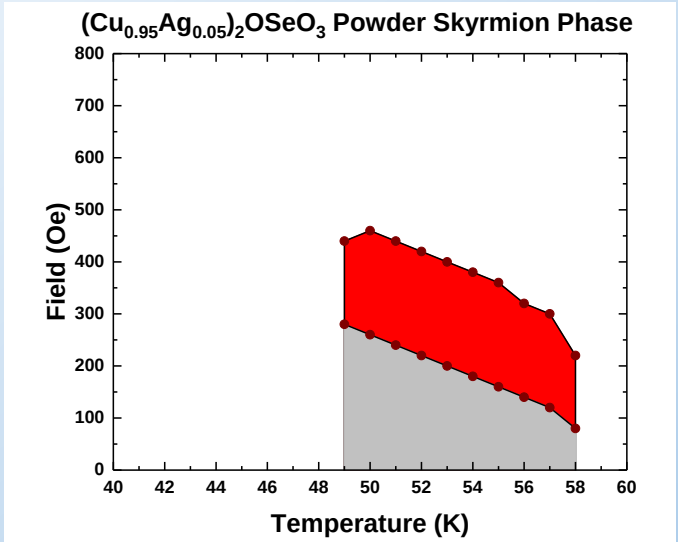


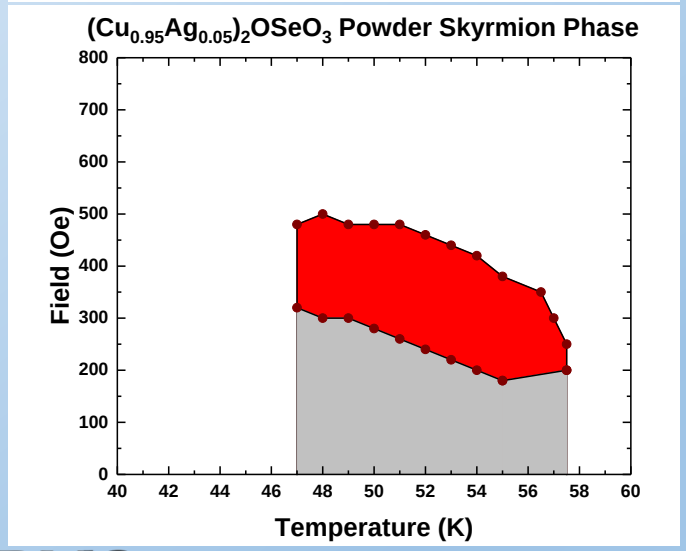
Wu, H. C. *et al.*

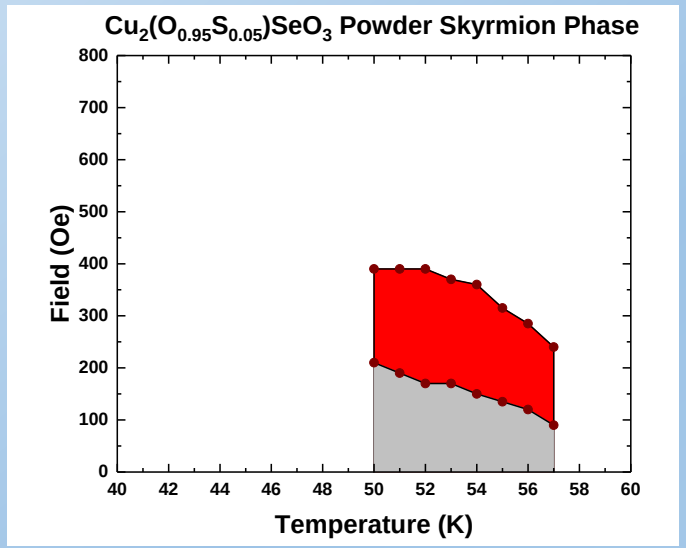


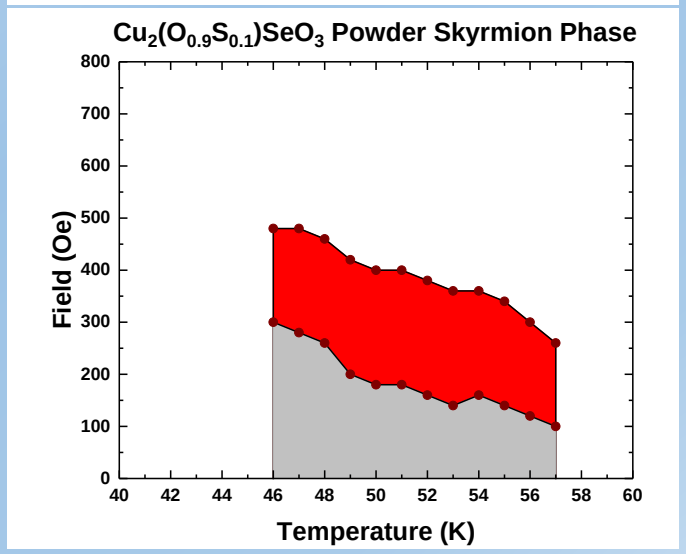
Other Substitutions

+Ag









+S

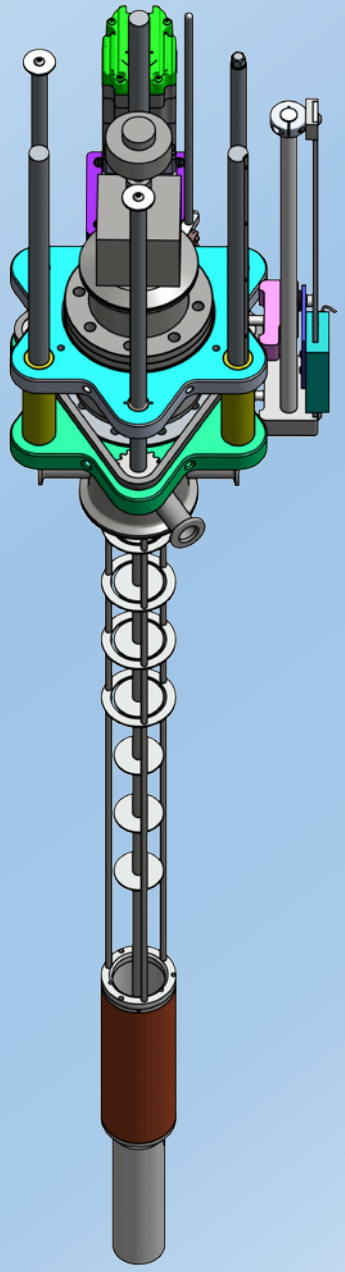
Summary

- Recent Work
  - Synthesized samples
  - Performed SANS measurements and analysis on parent and substituted powders
- Results
  - **Possible structural confirmation of second phase in Zn substitution**
  - **Can identify and map skyrmion phase in a powder**
- Future Work
  - Rotation of Zn substitution in SANS
  - Perform supplementary measurements
  - Investigate other substitutions further

Acknowledgements

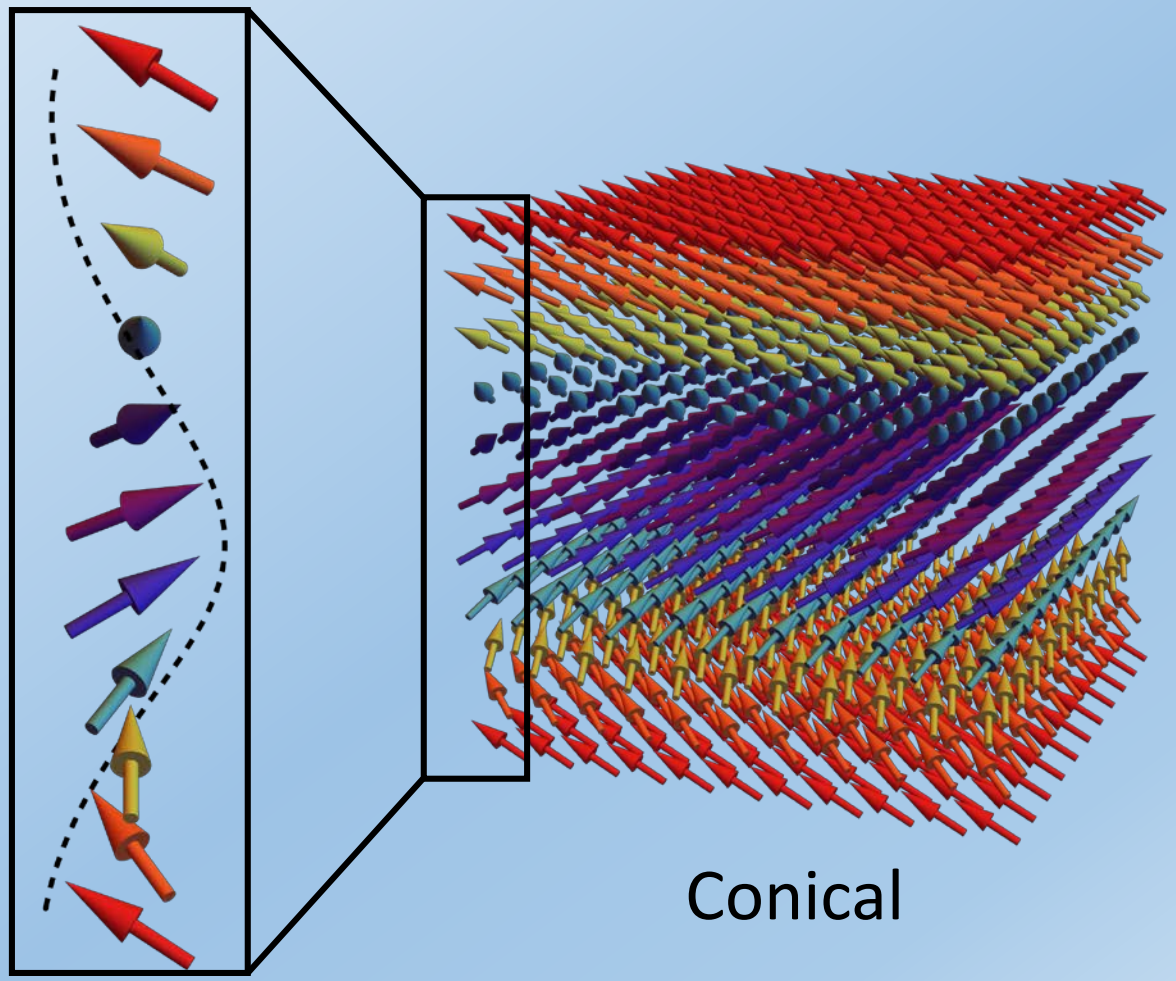
- NG7-SANS
  - Dustin Gilbert, Julie Borchers, Markus Bleuel, Jeffrey Krzywon, Tanya Dax
- MPMS Magnetometry
  - Sheng Ran, I-Lin Liu, Shanta Saha
- Sample Growth
  - Kefeng Wang, Sheng Ran
- MANiACS
  - Doug Johnson, Patrick Connelly, Scott Slifer, Colin Wrenn, Andrew Malone

Shameless Plug



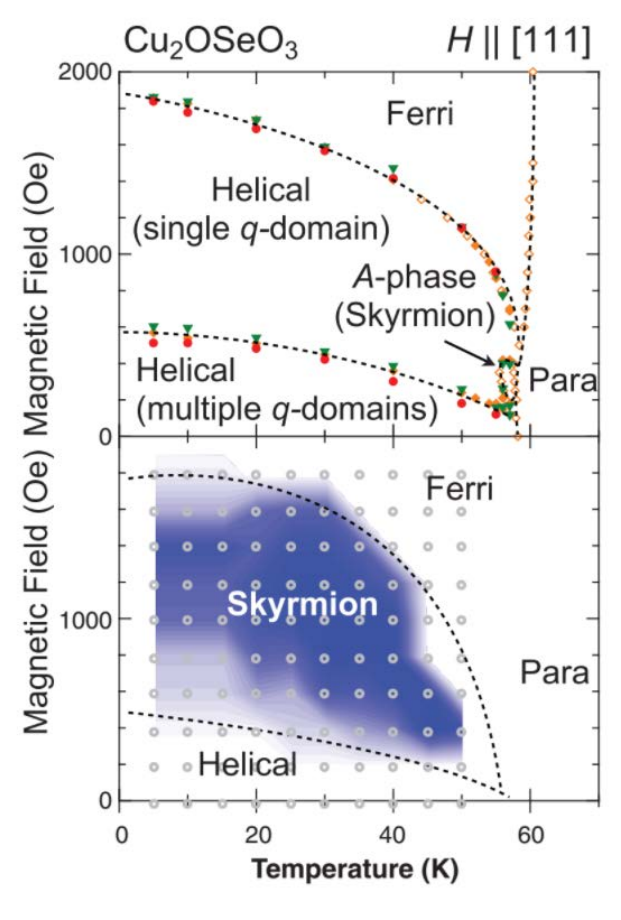
https://www.nist.gov/blogs/taking-measure/surfing-susceptometers-skyrmions-making-neutron-maniac

Magnetic Structures

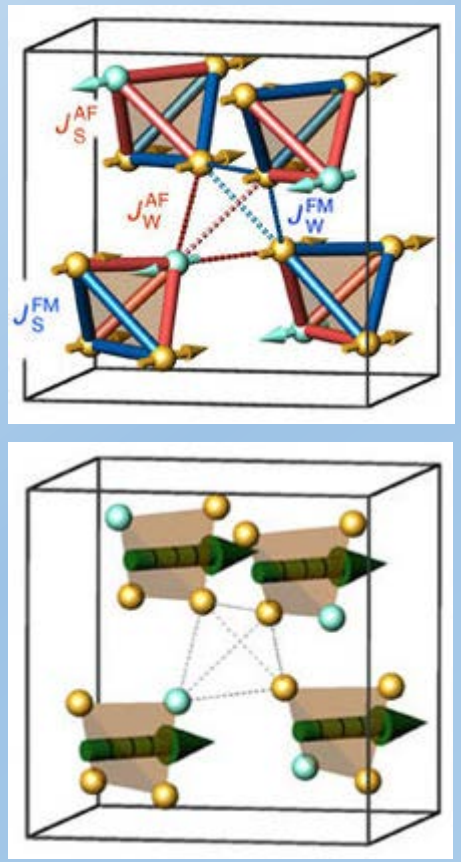


Conical

An Interesting Material: Cu_2OSeO_3

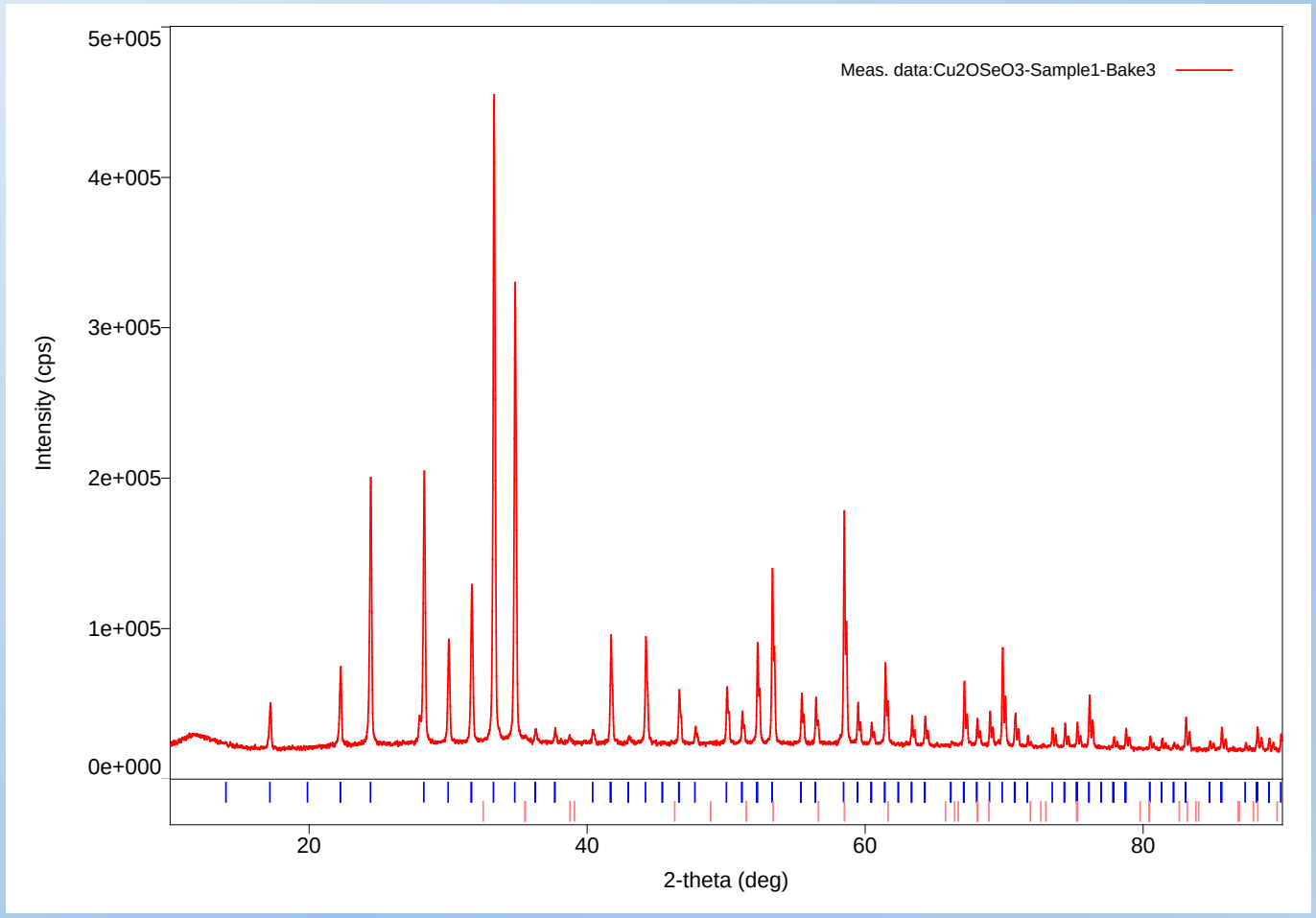


Seki, S. *et al.* Observation of Skyrmions in a Multiferroic Material. *Science* **336,** 198-201 (2012)

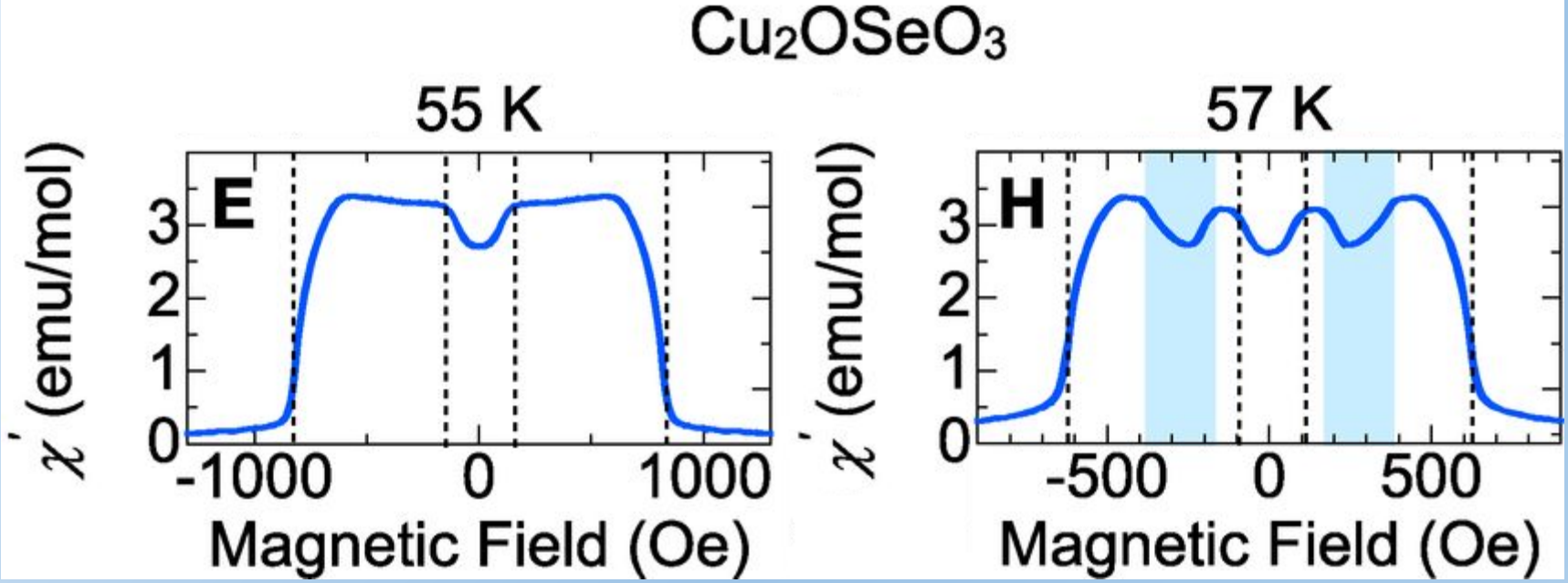


Janson, O. *et al.* The quantum nature of skyrmions and half-skyrmions in Cu_2OSeO_3. *Nature Communications* 5**,** (2014)

X-Ray Powder Diffraction

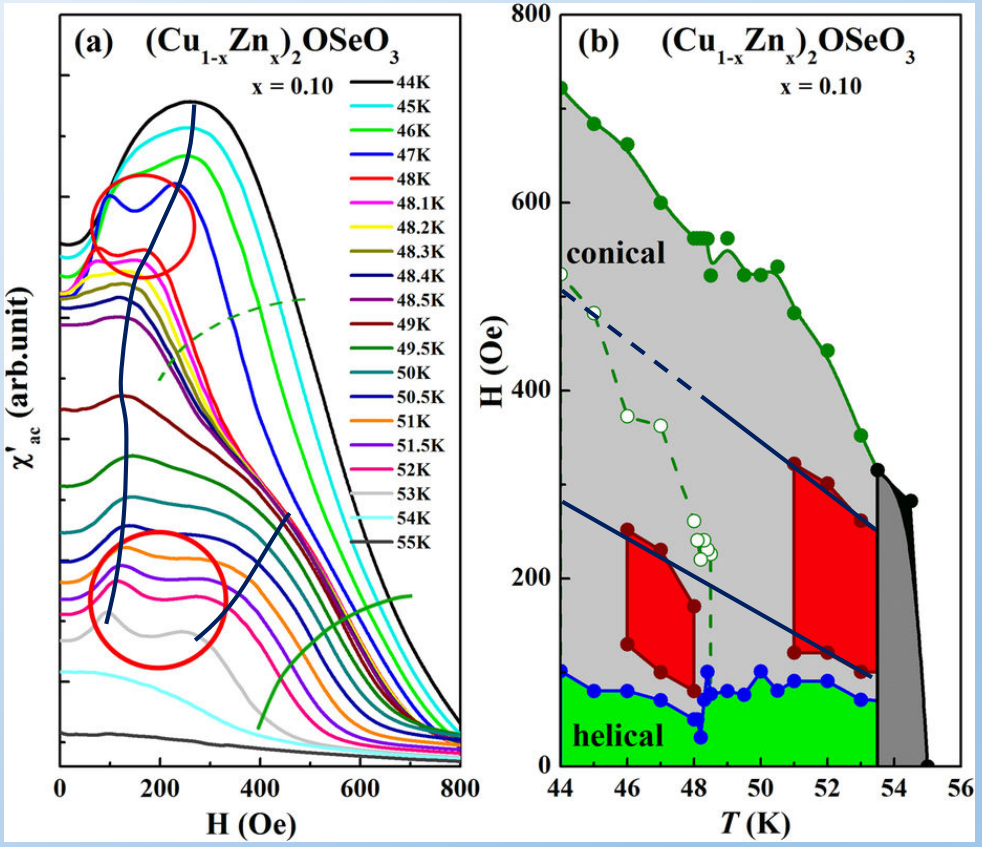


Magnetization: Parent

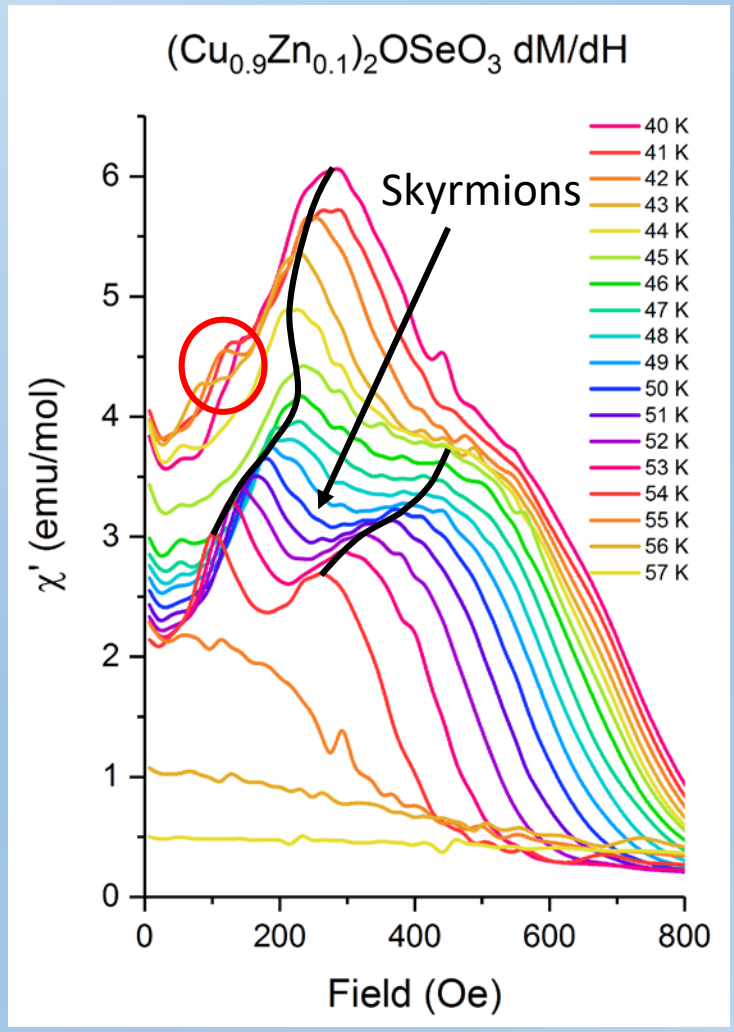


Seki, S. *et al.* Observation of Skyrmions in a Multiferroic Material. *Science* **336,** 198-201 (2012)

Magnetization: Zn Doped

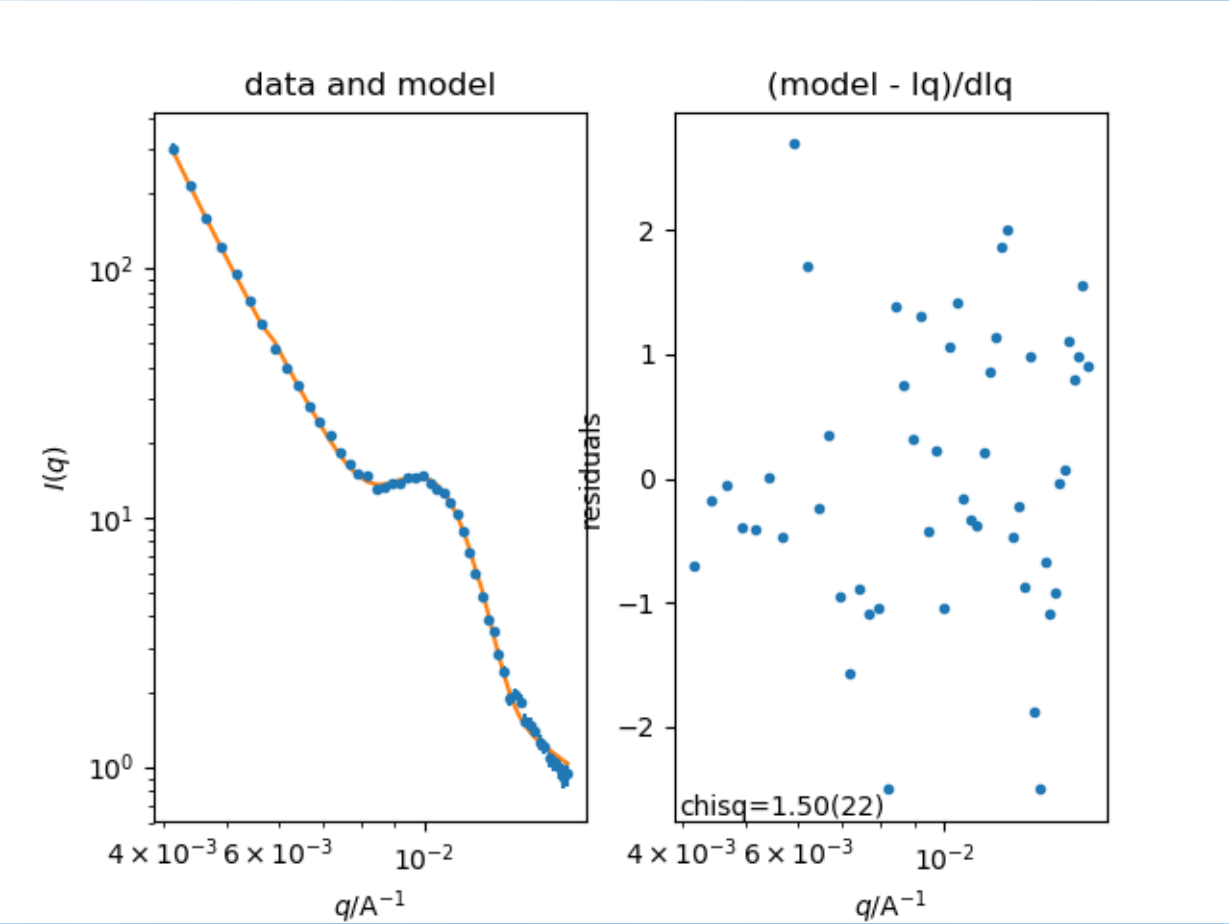


Wu, H. C. *et al.* Unexpected Observation of Splitting of Skyrmion Phase in Zn Doped Cu_2OSeO_3. *Science Reports* **5,** (2015)



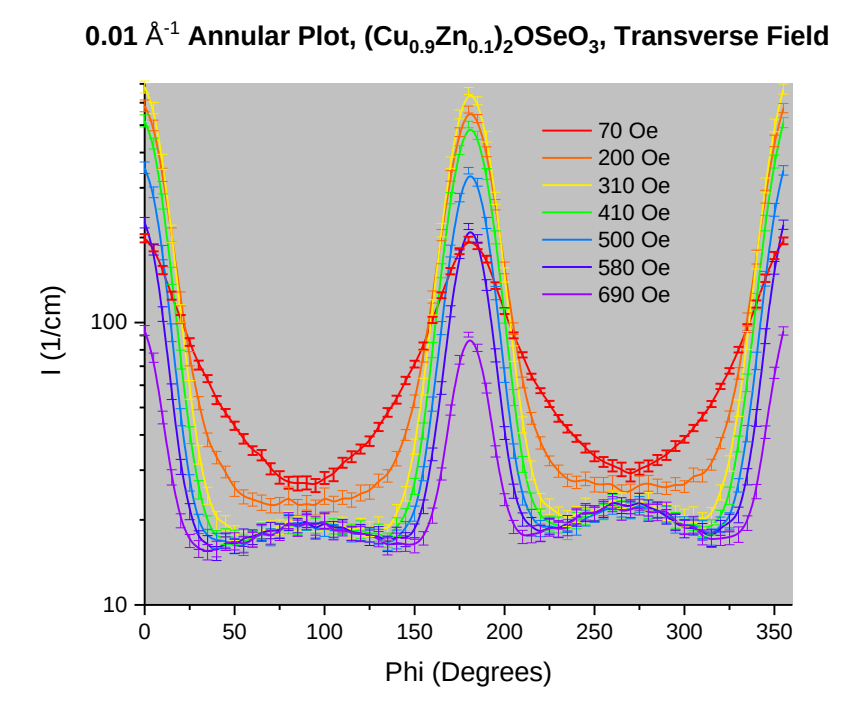
Our data

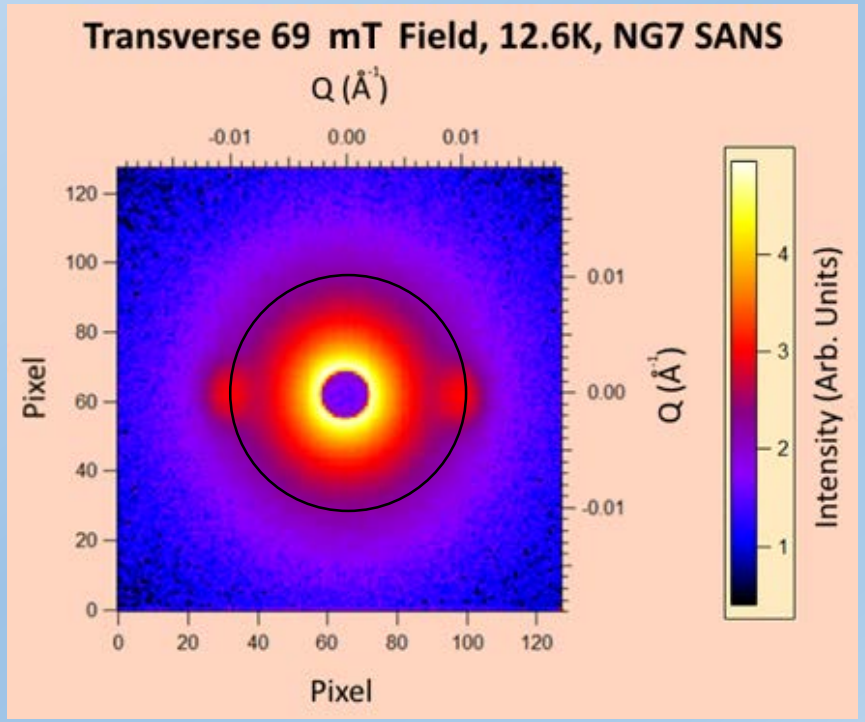
SANS: Zn Doped, H On Axis



Parameter	mean	median	best	[68% interval]	[95% interval]
1	A	17.2(39)	15.94	16.21 [13.8 21.3]	[12.5 28.1]
2	G	43(32)e3	38300	30300 [11000 73000]	[4000 113000]
3	background	0.65(22)	0.680	0.619 [0.43 0.86]	[0.14 1.06]
4	peak_pos	0.01014(12)	0.010144	0.010185 [0.01000 0.01025]	[0.00991 0.01038]
5	porod_exp	4.54(30)	4.511	4.480 [4.26 4.85]	[3.93 5.13]
6	rg	1.33(17)e3	1401.9	1193.0 [1202 1479]	[850 1495]
7	s	0.102(85)	0.072	0.012 [0.02 0.19]	[0.01 0.29]
8	sigma	0.78(21)e-3	0.000790	0.000779 [0.00054 0.00103]	[0.00042 0.00112]

SANS: Zn Doped, Transverse H, 12K





B