Resolving 2D Structure of Prospective Quantum Topological Magnets

Bianca Swidler

Physics Deptartment at Princeton University

Hasan Research Group
Laboratory for Topological Quantum Matter & Advanced Spectroscopy

Hasan Research Group
Laboratory for Topological Quantum Matter & Advanced Spectroscopy

Objectives

As a new scientist in the lab and in the area of quantum topological magnets, my summer objectives consisted of:

- Study **topology** and its relation to fundamental, non-relativistic quantum mechanics in condensed matter.
- Learn about the **Scanning Tunneling Microscope** and its functionality; train on the scanning tunneling microscope.
- Identify topological markers (e.g. **Landau Levels**) found in condensed-matter analysis.
- Analyze data–**lattice image** and **Landau Levels**–from new magnets to determine topological quantum candidacy.

Introduction

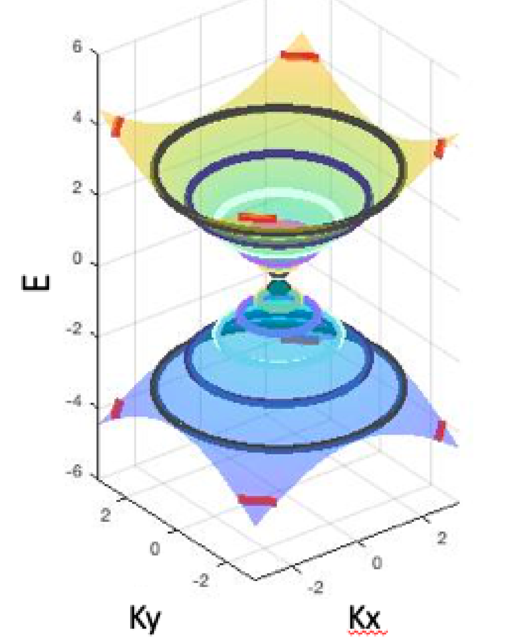


Figure: Dirac Cone Landau Levels

Quantum Topological materials are a class of matter that maintains quantized (discrete) properties under topological (smooth) deformation. To characterize materials that have such a property, **we have resolved the 2D structures (Landau Levels) of new quantum topological mangets**.

In 2016, the **Nobel Prize** committee awarded the prize in physics to the discovery of topological properties preserved even under disturbances at the quantum-mechanical level. Meanwhile, the **United States Department of Defense** has over the last decade offered generous paydays to teams researching these materials, their properties and potential applications.

The topological quantum properties found in both novel and common materials will be utilized to further develop technologies (e.g. more durable **quantum computing**). A fundamental understanding of how these materials behave at the subatomic level is paramount to exploiting such properties.

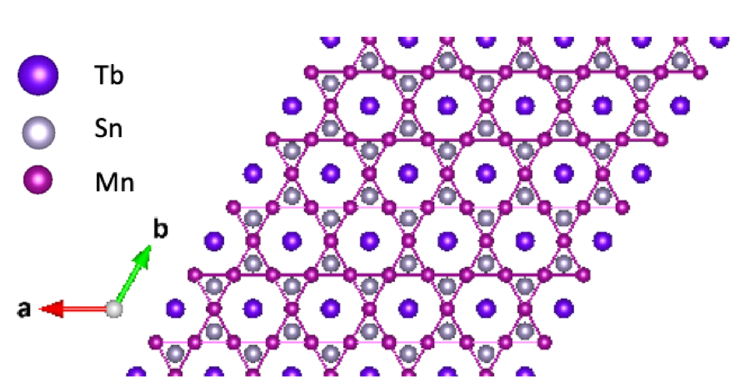


Figure: TbMn6Sn6 Crystal Structure

Methods

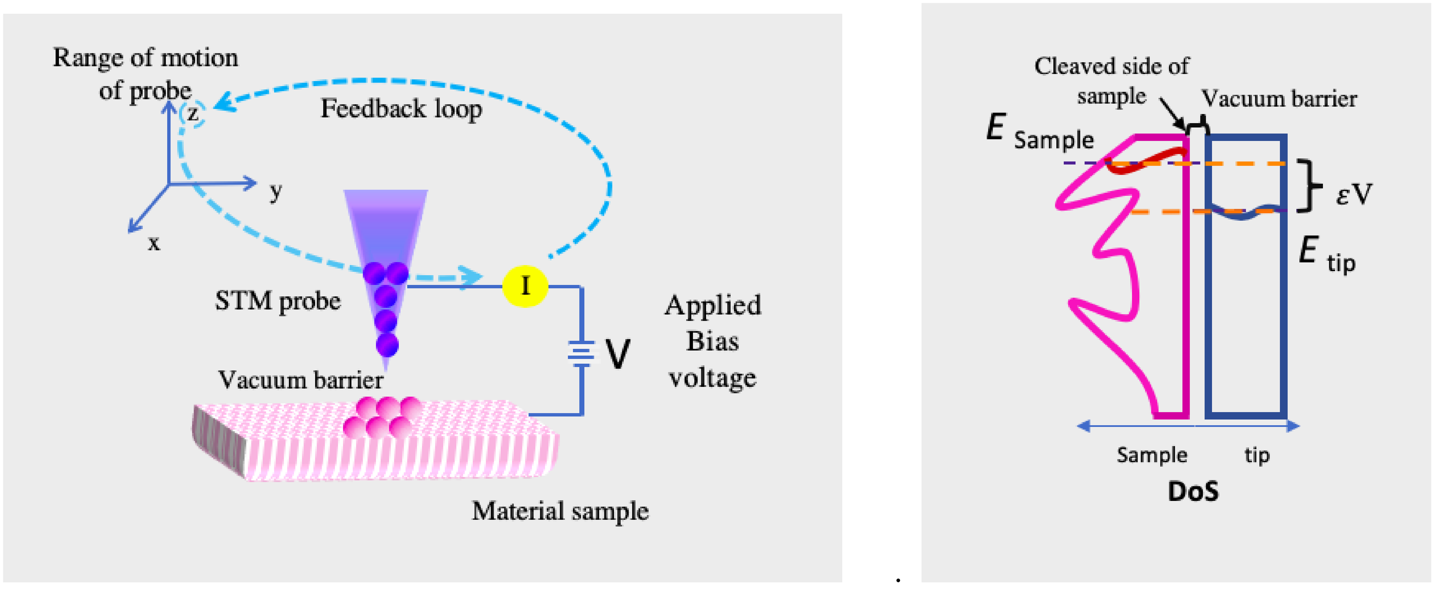


Figure: **Scanning Tunneling Microscopy**: A potential bias is applied between sample and tip, generating a tunneling current I. (at left) I is correlated with the sample-tip tunneling distance, so this information is fed through a feedback loop to maintain relative distance. This changes the absolute tip height, gathering atomic structure information about the sample. (at right) Quantum tunneling phenomenon responsible for scanning tunneling microscope functionality.

Significant Result

By using scanning tunneling microscopy, **Landau-Level peaks were observed in TbMn6Sn6**, a new Topological Quantum magnet candidate. These filled landau levels suggest the material's topology is preserved, which has exciting implicatiions for its utility in materials science.

Mathematical Basis

The wavefunctions for each microscope tip and material are solutions of form

$$\psi(z) = \psi(0)e^{\frac{-iE_m t}{\hbar}} \quad (1)$$

The most general solution in the gap region for the combined system is

$$\psi(z) = \psi(0)e^{-\kappa z} \quad (2)$$

where $\kappa = \frac{\sqrt{2\pi\epsilon}}{\hbar}$.

The Integrated Density of States (IDoS) can be interpreted from this and, making appropriate approximations for DoS of microscope probe, perturbation element, and Fermi distribution bring us to **Density of States**

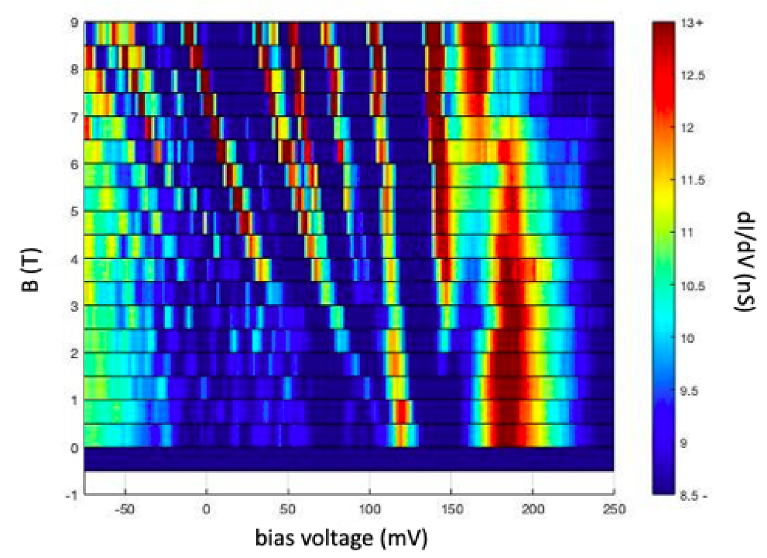
$$\frac{dI}{dV} \propto \rho_s(\epsilon + eV) \quad (3)$$

where the differential current is analyzed against applied potential bias to identify Landau Levels.

Materials

The Scanning Tunneling Microscope is used in tandem with spectroscopy computer and software. Data processing and data analysis software used. Sample TbMn6Sn6 analyzed from lab.

Results



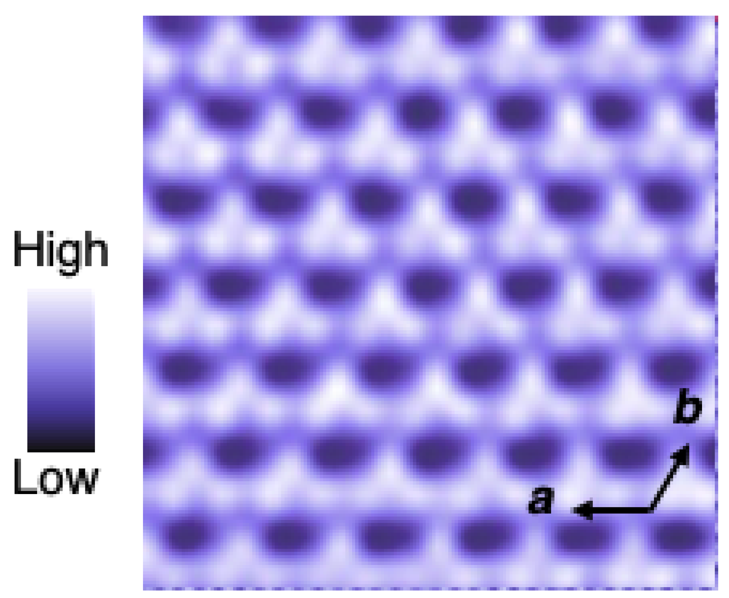


Figure: **Structural information of TbMn6Sn6**: (above) Landau-Level fan demonstrating clear, consistent peaks at different potential bias intervals. (below) 2D atomic structure, created from real sample using a current feedback loop. Demonstrates modeled Kagome lattice structure.

Conclusion

The landau levelss detected in TbMn6Sn6 are defined well, suggesting it may be a good topological magnet candidate. This research inches us closer to defining the theoretical basis for quantum topology and how it may be beneficial in developing society. Further research will focus on determining the magnet's classification as well as establishing a theoretical basis for topological behavior.

Additional Information

My research opportunity was graciously funded through the SRC ReMatch+ program. This research will be ongoing in the Hasan group at Princeton University. I will continue this work and work toward original research in the same group through Fall 2019-2020. Further information on my related individual research can be accessed at https://www.overleaf.com/read/dndxpjcrfmdz.

References

Please visit https://www.overleaf.com/read/dndxpjcrfmdz for full citation.

Acknowledgements

Thank you to Jiaxin Yin for being my SRC ReMatch+ mentor, scholarly guidance and advice. Thank you to Songtian Sonia Zang for orienting me to the lab and scholarly guidance, and to Nana Shumiya for her insight. Thank you to my PI Prof. M. Zahid Hasan for his mentorship and availability for assistance. A thank-you to the SRC and ReMatch+ programs, Dr. Poussart and Dr. Choi for their assisstance in all things SRC and mentorship. And thank you to my family for invaluable love, support and laughs along the way.

Contact Information

- Web: http://physics.princeton.edu/zahidhasangroup/
- Email: bswidler@princeton.edu
- Github: biancaswidler