

Ferrimagnetic Garnet Targets for Exotic Force Searches

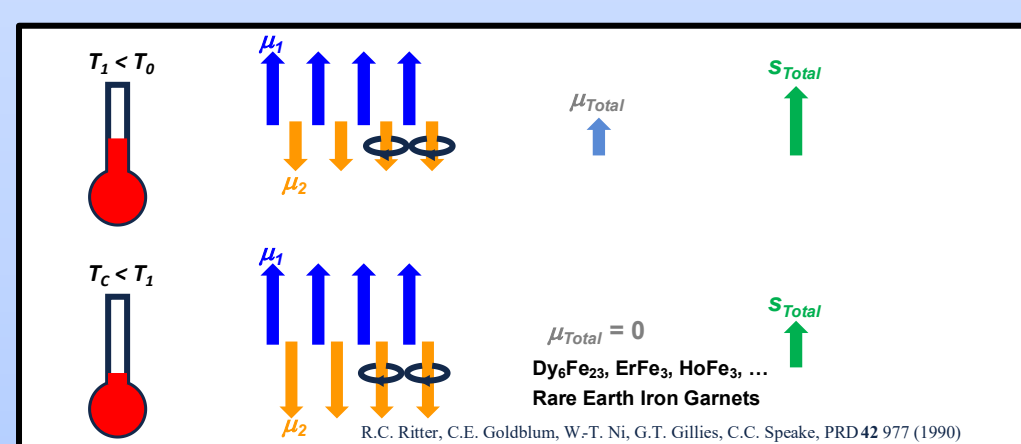
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INTRODUCTION & AIM

The Neutron Spin Rotation in Ferrimagnets Experiment is a collaborative effort to probe boson-mediated exotic forces between electrons and neutrons using a polarized ferrimagnetic target with spin but no magnetism. Our sample is bulk polycrystalline terbium iron garnet (TbIG), with molecular formula $Tb_3Fe_3O_{12}$. The rare-earth and iron sublattices are anti-aligned with different temperature dependences, and their magnetic moments cancel each other out at a particular temperature known as the compensation temperature (T_{comp}). However, as shown in Fig. 1, due to the small orbital component of the rare-earth moment, the spin moment doesn't completely cancel at T_{comp} .



The theoretical exotic force couples to the interaction between this spin excess and the spin of the neutrons on the beam. Precise knowledge of the spin excess in our TbIG sample is vital for constraining exotic forces, and that's the underlying motivation of this paper.

METHOD

We start by modeling the magnetization vs temperature of TbIG with a mean-field model, using the interactions between the molecular sublattices, described in detail in [1] and plotted in Fig. 2. Comparing the total model magnetization with temperature sweep data from our own synthesized polycrystalline garnet, the model moment is $\sim 2\times$ larger than the measured value (Fig. 3).

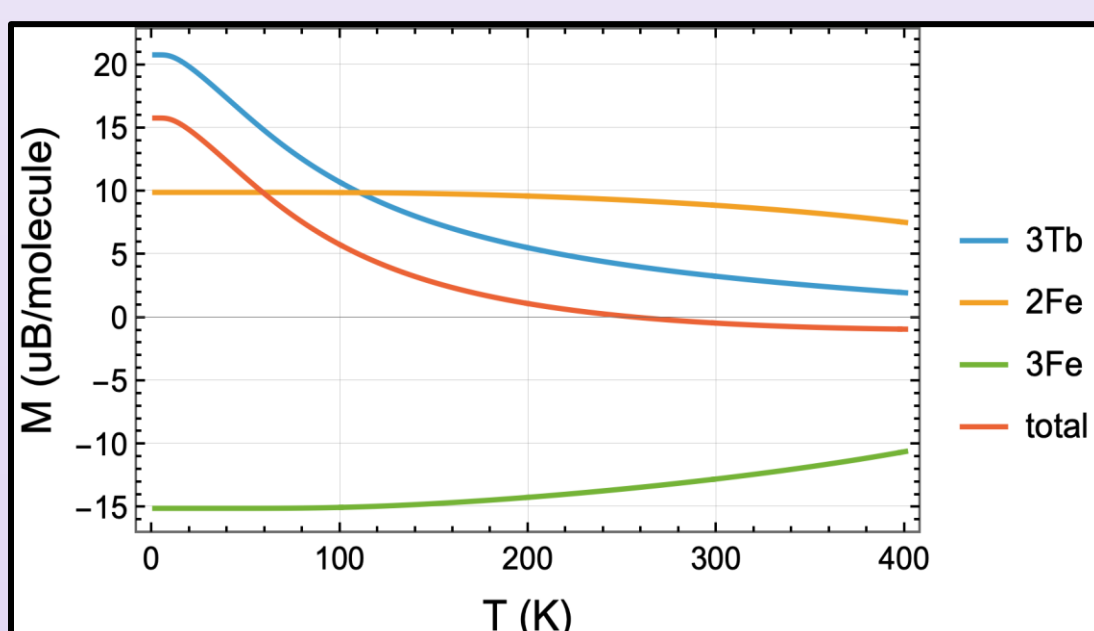


Fig. 2: Moment vs temp model for TbIG sublattices

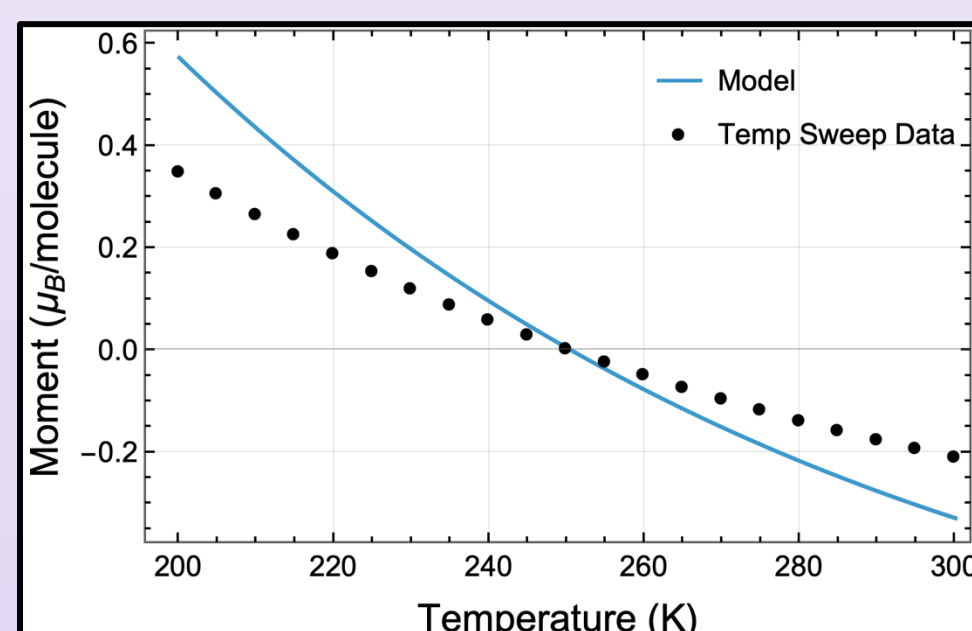


Fig. 3: Moment vs temp for model and data

This is expected, since the model is based on the spontaneous moments, but we measure the remanent moments. The difference can be seen in Fig. 4-5, where the remanent is the zero-field measurement, and the spontaneous moment is extrapolated to 0 from high-field hysteresis curves. To reconcile the data with the model, we find the ratios between remanent and spontaneous moments, and multiply the model by that ratio. To reach our initial goal of obtaining the spin excess, we simply take the summed spin excess from the sublattice components and multiply that by the ratio at the specified temperature.

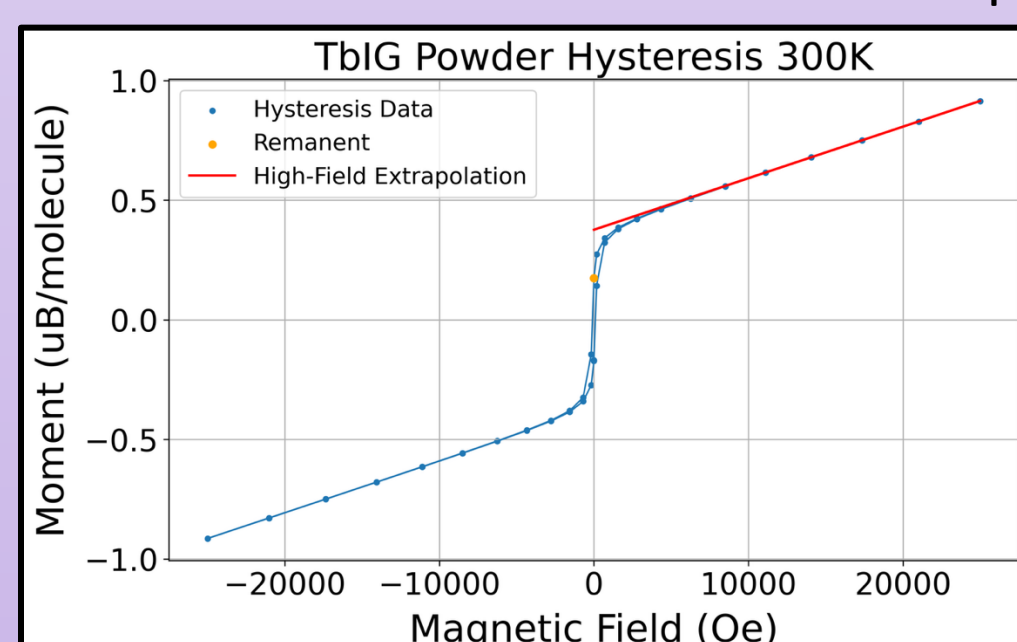


Fig. 4: Moment vs field for TbIG at room temperature

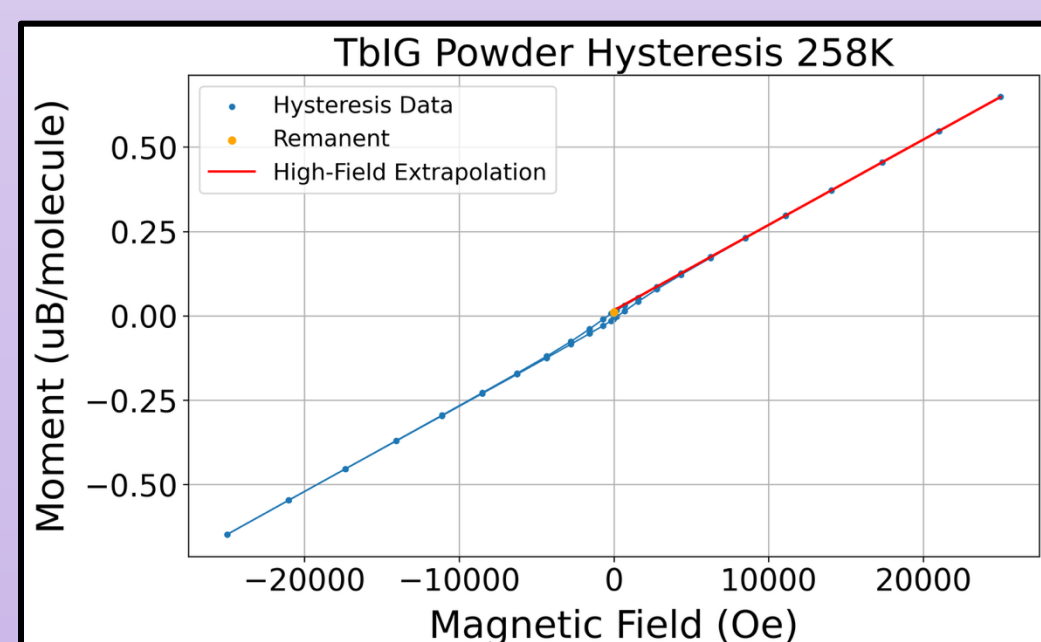


Fig. 5: Moment vs field for TbIG at room temperature

RESULTS & DISCUSSION

The measured remanent to spontaneous moment ratios are shown in Fig. 6. The ratio stays around 0.6 to 0.7 around T_{comp} , and peaks very close to T_{comp} . Fig. 7 shows the mean field model plot after being multiplied by the remanent ratios. We see a very good agreement between the two above 230K and below 290K, which indicates that our method is reliable for the temperature region we are concerned with.

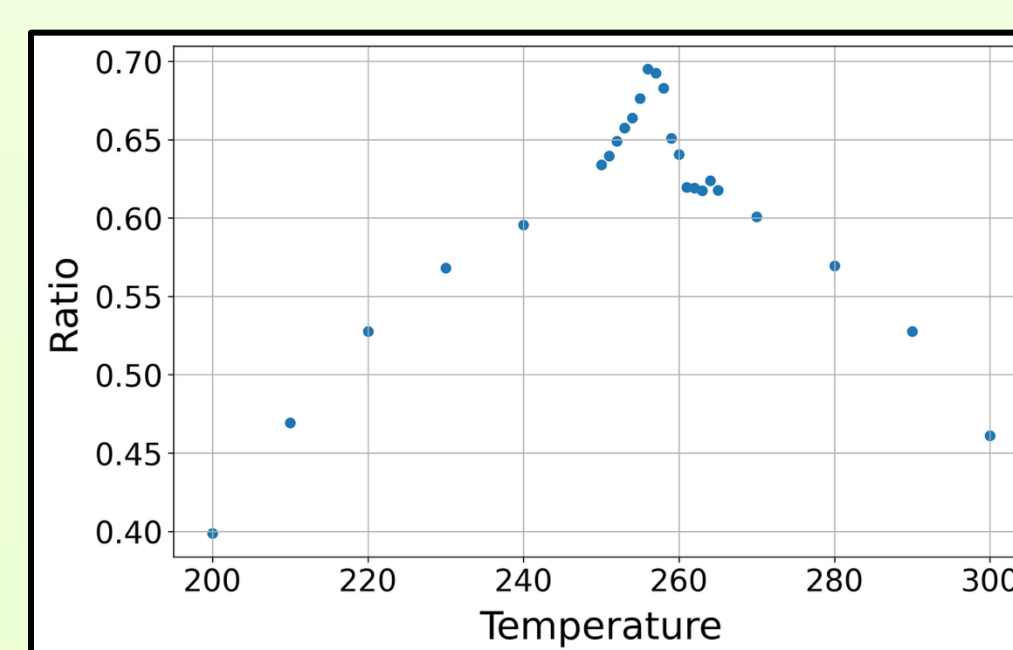


Fig. 6: Remanent ratio vs temperature

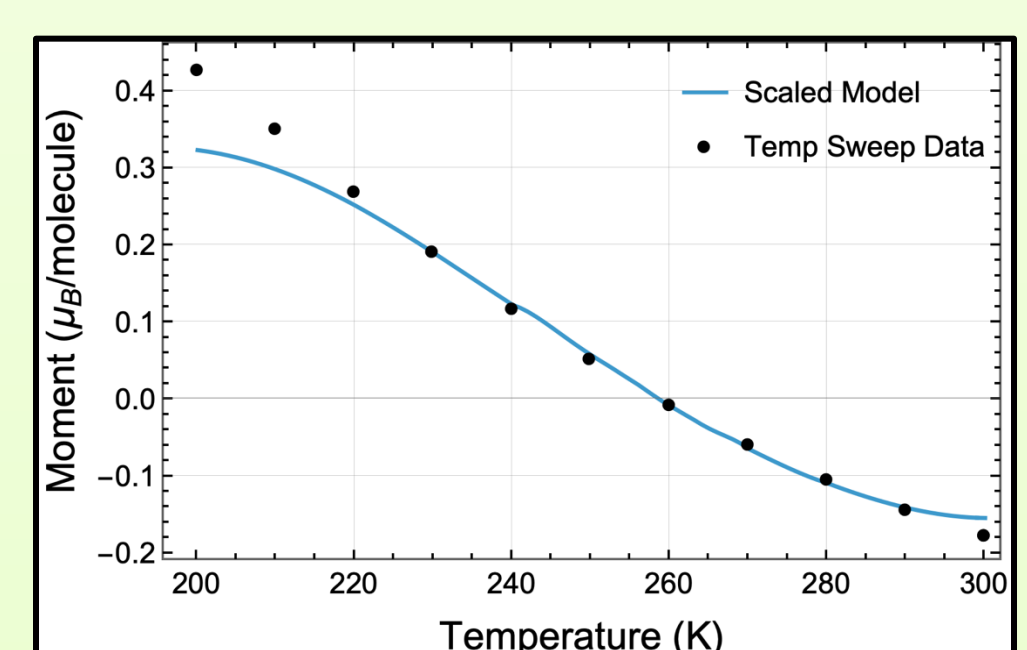


Fig. 7: Scaled model vs data

Further confirmations comes when comparing with measured spin rotation values taken at Oak Ridge HFIR. This completely independent measurement matches with the mean field model very well, after the model results are converted to spin rotations using a simple 2D field integration along the beamline (Fig. 8).

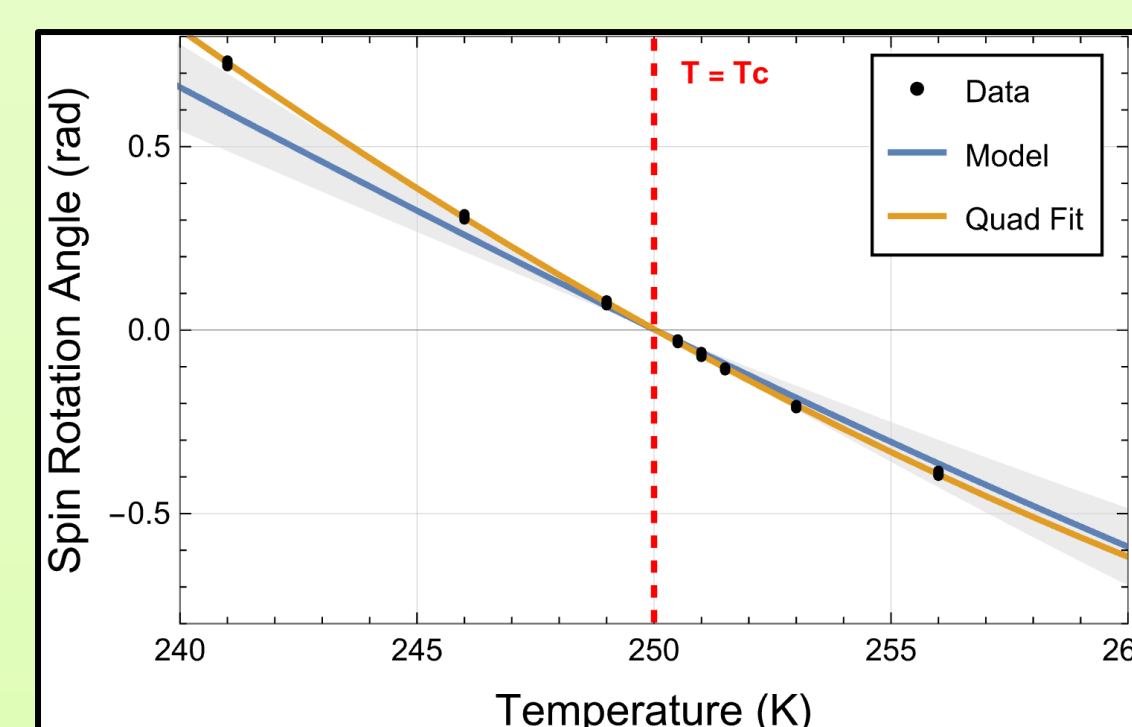


Fig. 8: Spin rotation vs temperature. The neutron spin is affected by the magnetic field inside and around the sample.

Finally, multiplying the modeled spin excess at T_{comp} by the remanent ratio at that temperature (0.70), we find a spin excess of $-0.36 \mu_B/\text{molecule}$ for a 100% pure TbIG sample.

Especially after applying further corrections for sample purity, this spin excess value is relatively low. Figuring out how to fabricate a single-crystal sample might give a factor of 2 increase, but gaining an order of magnitude from the spin density would require the use of a new type of ferrimagnet.

CONCLUSION

By applying a correction factor based on the remanent ratio, the ferrimagnet molecular field model can make accurate predictions on measured magnetic moment data and thus predict the spin density of rare-earth iron garnets at various temperatures. This can be used to apply more precise constraints on exotic spin-dependent forces.

FUTURE WORK / REFERENCES

Magnetic Compton scattering measurements at the Spring-8 beamline will provide a test for this model and spin density calculation.

[1] T. M. Leslie, E. Weisman, R. Khatriwada, and J. C. Long, Phys. Rev. D, 89, 114022 (2014).